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Stratigraphy, Sedimentology, and Petrology of the Huronian Supergroup in the Sudbury - Espanola Area

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By

K. D. Card, D. G. Innes, and R. L. Debicki

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ABSTRACT

The stratigraphy, sedimentology, and chemistry of the Huronian Supergroup, a Middle Precambrian assemblage of sedimentary and volcanic rocks, are described in the region southwest of Sudbury, Ontario bounded by Latitudes 46°00′N to 46°30′N and Longitudes 81°00′W to 82°00′W. Data were gathered in the field and from published literature and theses. A number of stratigraphic sections of the various Huronian formations were measured and described; summary descriptions are given herein. A formal stratigraphic subdivision of the lower, predominately volcanic part of the Huronian Supergroup in the Sudbury area is proposed.

Stratigraphy, Sedimentology, and Petrology of the Huronian Supergroup in the Sudbury-Espanola Area,

by

K. D. Card,[1] D. G. Innes,[2] and R. L. Debicki[3]

INTRODUCTION

It seems to me that the areas of our disagreement and uncertainty are largely the result of our lack of knowledge about the rocks themselves. Up to this moment the greatest efforts have been expended in mapping and establishing a stratigraphic and structural framework. This is as it should be and is most necessary. The time has now arrived to look at the rocks themselves. A good beginning has been made in the past decade but many formational units have never had a proper study. The lack of elemental data – such as modal and chemical analyses, measured sections, paleocurrent data – on just "what's there" are lacking. Until such studies are made, our ability to synthesize and interpret Huronian history will remain unsatisfactory and incomplete.

The above statement, made by F. J. Pettijohn (Pettijohn 1970, p.264) shows the necessity of having quantitative sedimentological, stratigraphic, and chemical data for making genetic interpretations and comparisons between Huronian rocks and younger, unmetamorphosed sequences on the one hand, and highly metamorphosed rocks of suspected similar origin on the other. Much of the required data are available, but are scattered through a number of published and unpublished reports, papers, and theses. The purpose of this paper is to bring together much of the available data on the Huronian of the Sudbury-Espanola area bounded by Latitudes 46°00′N to 46°30′N and Longitudes 81°00′W to 82°00′W (see inset map on Charts A, B, C and D, back pocket). A major regional problem, the age and stratigraphic relationship of the basal volcanic rocks and turbidites ("Sudbury Series") with the remainder of the supracrustal sequence, which is dominated by "shelf-type" sandstones occurs, and must be resolved here. The various conflicting interpretations of this and other problems as outlined by Collins (1925; 1936),

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Cooke (1946), Thompson (1953; 1957; 1962), Young and Church (1966), Robertson, Card, and Frarey (1969), Robertson, Frarey, and Card (1969), and Roscoe (1969), can be mainly attributed to a lack of knowledge of "what is there". The stratigraphic and sedimentological data given by the authors here should reduce the gaps in our knowledge. This report also partly fulfills the recommendations of the Federal-Provincial Committee on Huronian Stratigraphy (Robertson, Card, and Frarey 1969; Robertson, Frarey, and Card 1969) for detailed stratigraphic descriptions and establishment of type sections for various formations of the Huronian Supergroup. The inset map on Charts A, B, C and D (in back pocket) is a geological sketch-map of the Sudbury-Espanola area, Ontario, and has the locations of the measured stratigraphic sections marked on it. Summaries of the stratigraphic sections are given in the section on "Stratigraphic Sections". The sources of much of the data presented are listed in the references at the end of the report.

GENERAL GEOLOGY OF THE HURONIAN SUPERGROUP

The Huronian Supergroup of the Southern Province, a Middle Precambrian (Aphebian) assemblage of sedimentary and volcanic rocks, overlaps northward onto a basement of Early Precambrian rocks of the Superior Province (Stockwell *et al.* 1970). The Huronian sequence was deposited at some time during the interval 2,500 million years, the minimum radiometric age of the Early Precambrian felsic plutonic basement, and 2,150 million years, the rubidium-strontium radiometric age of intrusive Nipissing Diabase bodies (Van Schmus 1965). Radiometric dating of Huronian metasediments and metavolcanics themselves suggests that they were deposited approximately 2,300 million years ago (Fairbairn *et al.* 1969; Knight 1965).

The Huronian Supergroup in the Sudbury-Espanola area has a total cumulative thickness in excess of 35,000 feet (10 700 m) and is the thickest, most complete section of the sequence in existence. In contrast, the total thickness of the Huronian of the Sault Ste. Marie-Elliot Lake and Cobalt-Sudbury areas is about 15,000 feet (4 600 m), and in many localities the lower part of the succession is absent (Card *et al.* 1972). Much of the southward thickening of the Huronian is quite abrupt across zones now marked by major faults of the Murray Fault System.

A great part of the Huronian sequence shows cyclical repetitions of conglomerate, pelite and greywacke, and quartz-feldspar sandstone units (Figure 1). This cyclicity leads to the scheme of stratigraphic subdivisions involving four groups of formations given in Table 2 of Robertson, Card, and Frarey (1969). The basal Elliot Lake Group ("Sudbury Series" of Coleman 1914) lies unconformably on an irregular erosion surface developed on Early Precambrian basement rocks. On a regional scale, the paleolimits of successively younger formations advance progressively northward; where the younger groups overlap onto the Early Precambrian basement, they lie on an irregular erosional unconformity (Roscoe 1969).

The Elliot Lake Group comprises an interfingering sequence some 10,000 feet (3 000 m) thick of feldspathic sandstone and conglomerate (Matinenda Formation), greywacke and pelite (McKim Formation), and mafic and felsic volcanic rocks (Elsie Mountain, Stobie, and Copper Cliff Formations). The Matinenda Formation consists of coarse feldspar-rich sandstone with lenses of uranium-bearing

quartz-pebble conglomerate. The McKim Formation is a thick accumulation of greywacke, siltstone, and aluminous pelite that shows features indicative of deposition by turbidity currents, such as; Bouma cycles (Bouma 1962), (Figure 2), graded beds, ripple marks, and cross-laminations.

The volcanic sequence consists of the following; subalkaline, tholeiitic, mafic, and felsic flows, pyroclastic rocks, associated intrusive rocks; and interflow sediments, which include greywacke, and aluminous and pyritic pelite. The sequence shows an overall mafic to felsic compositional trend and numerous cyclical repetitions of volcanic and sedimentary units. The volcanic accumulations, judging from their distribution and stratigraphy, apparently represent fissure-type eruptions whose emplacement was controlled by early marginal faults. The Elsie Mountain, Stobie, and Copper Cliff Formations represent one major mafic-felsic volcanic cycle. Felsic (Creighton Granite) and mafic (layered gabbro-anorthosite) plutons are related closely to the volcanic accumulations in time, space, and possibly, genesis.

The Hough Lake and Quirke Lake Groups comprise two cyclic repetitions of a lower conglomeratic unit (Ramsay Lake and Bruce Formations), a middle pelite-greywacke unit (Pecors and Espanola Formations), and an upper sandstone unit (Mississagi and Serpent Formations). The two groups thicken southeastward and reach a maximum total thickness of about 15,000 feet (4 600 m). The sandstone units are relatively uniform wedges of coarse, immature to submature feldspathic sandstone characterized by abundant crossbedding. The Pecors Formation is lithologically similar to the McKim Formation, whereas the Espanola Formation contains carbonate-bearing rocks. The Espanola rocks show many sedimentary structures, such as ripple marks, desiccation cracks, cross-laminations, crossbedding, flame structures, ball-and-pillow structures, intraformational breccias, slump folds, and clastic dikes. The Ramsay Lake and Bruce Formations consist mainly of massive or poorly bedded conglomeratic rocks composed of scattered plutonic rock fragments in a feldspathic greywacke matrix characterized by the presence of abundant, well-rounded quartz grains. Sedimentary structures are notably rare, although locally bedding, ripple marks, crossbedding, and 'drop stones' attest to deposition in water.

The Cobalt Group, consisting of the Gowganda, Lorrain, Gordon Lake, and Bar River Formations, has a maximum preserved thickness of about 17,000 feet (5 200 m). The Gowganda Formation, about 4,000 feet (1 200 m) thick, is a heterogeneous assemblage of conglomerate, feldspathic sandstone, siltstone, greywacke, and argillite. The Gowganda Formation is divisible into a lower unit of conglomeratic and pelitic rocks, and an upper well-bedded sequence of sandstone and siltstone. The conglomeratic rocks include massive and bedded paraconglomerate and orthoconglomerate, and are characterized by the presence of large, unsupported plutonic rock fragments, some of which have been dropped into laminated argillite-siltstone. The associated pelitic rocks, including siltstone, argillite, and fine-grained greywacke, are typically well bedded; some units have delicate parallel laminations, but other units are irregularly laminated and display ripple marks, cross-laminations, and Bouma cycles. The upper part of the Gowganda Formation consists of several sequences of siltstone and feldspathic sandstone which coarsen upward and contain abundant slump structures.

The Lorrain Formation is a remarkably thick (5,000 to 8,000 feet; 1 500 to 2 400 m), sandstone that consists of a lower sequence of immature feldspathic sandstone,

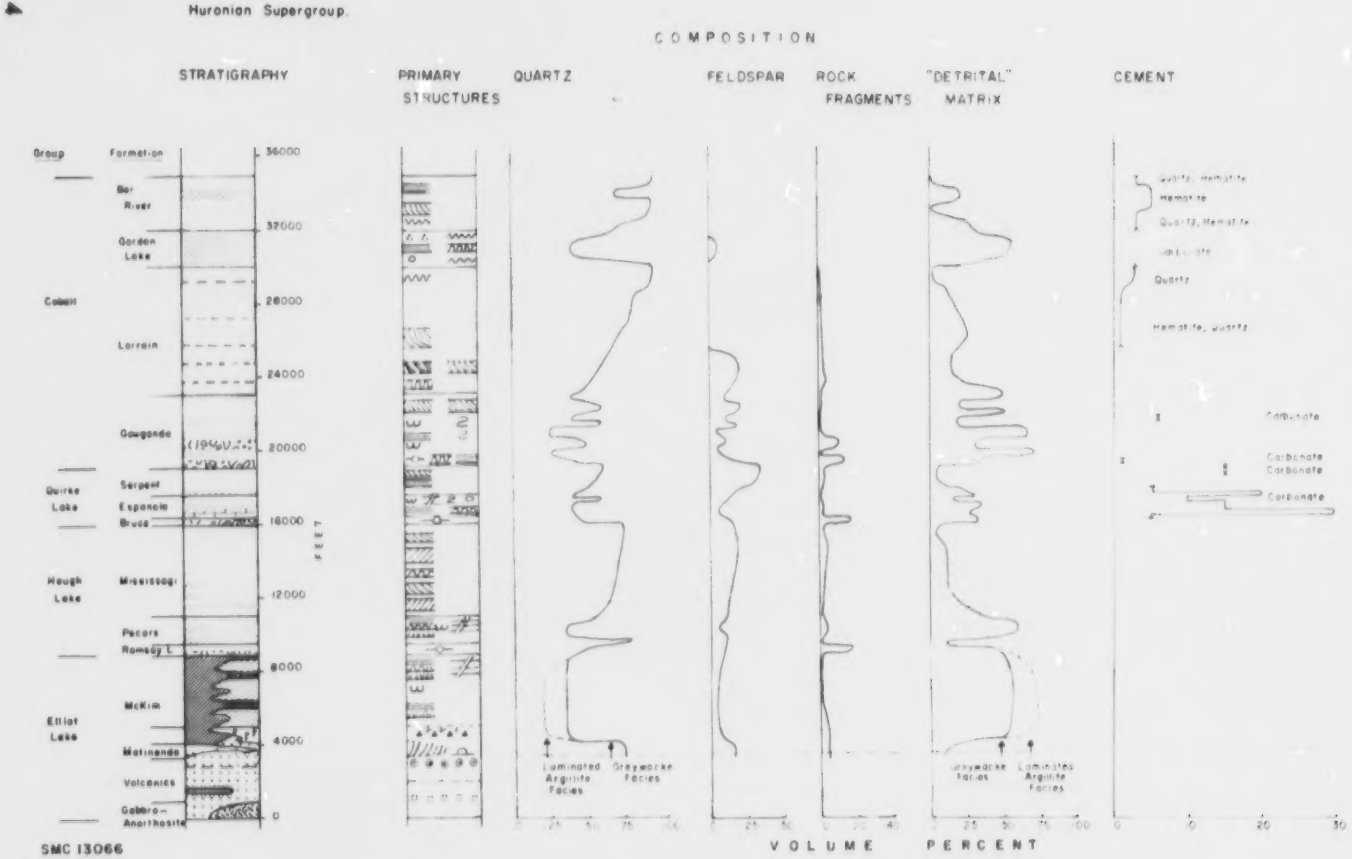
Huronian Supergroup
COMPOSITION
STRATIGRAPHY
PRIMARY STRUCTURES
QUARTZ
FELDSPAR
ROCK FRAGMENTS
"DETRITAL" MATRIX
CEMENT
Group
Formation
Bar River
Gordon Lake
Cobalt
Lorrain
Gowganda
Quirke Lake
Serpent
Espanola
Bruce
Hough Lake
Mississagi
Pecors
Romeo
McKim
Elliot Lake
Matinenda
Volcanics
Gabbro–Anorthosite
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
FEET
Laminated Argillite Facies
Greywacke Facies
Greywacke Facies
Laminated Argillite Facies
Quartz
Hematite, quartz
Carbonate
Carbonate
Carbonate
VOLUME PERCENT
SMC 13066
Huronian Supergroup — Sudbury-Espanola Area

Figure 1–Generalized stratigraphy, sedimentology, and facies interpretation of the Huronian Supergroup in the Sudbury-Espanola area.

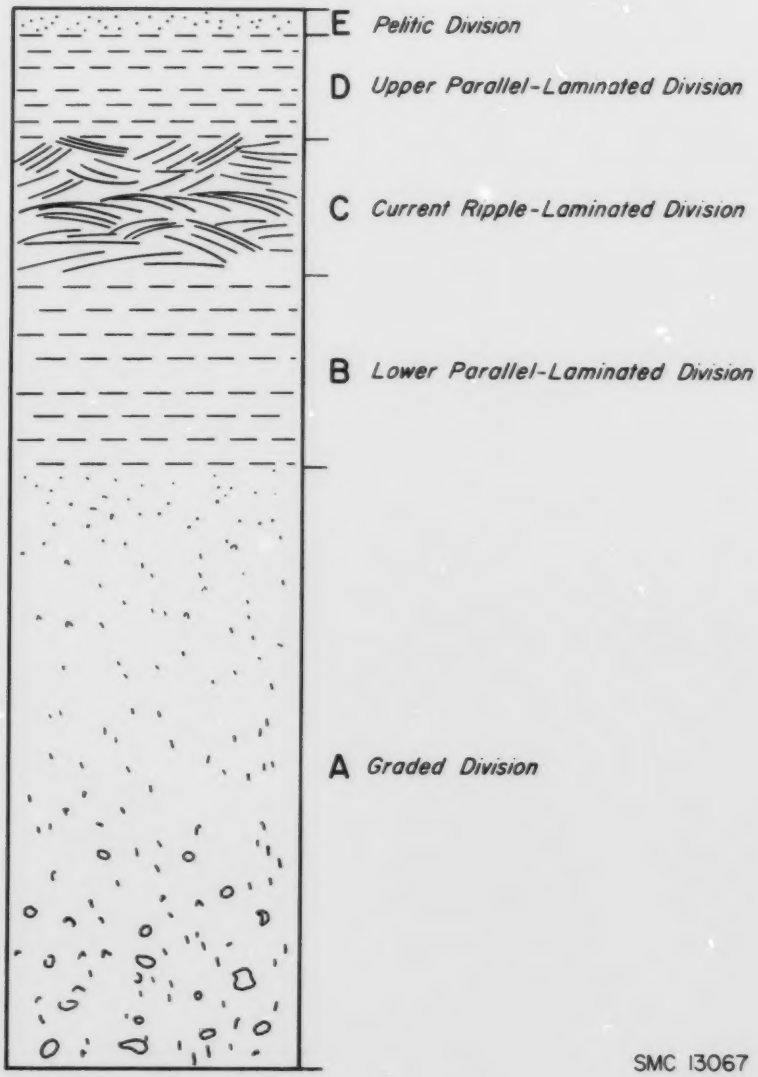

Figure 2–A complete Bouma cycle showing units A, B, C, D, and E; from Bouma (1962).

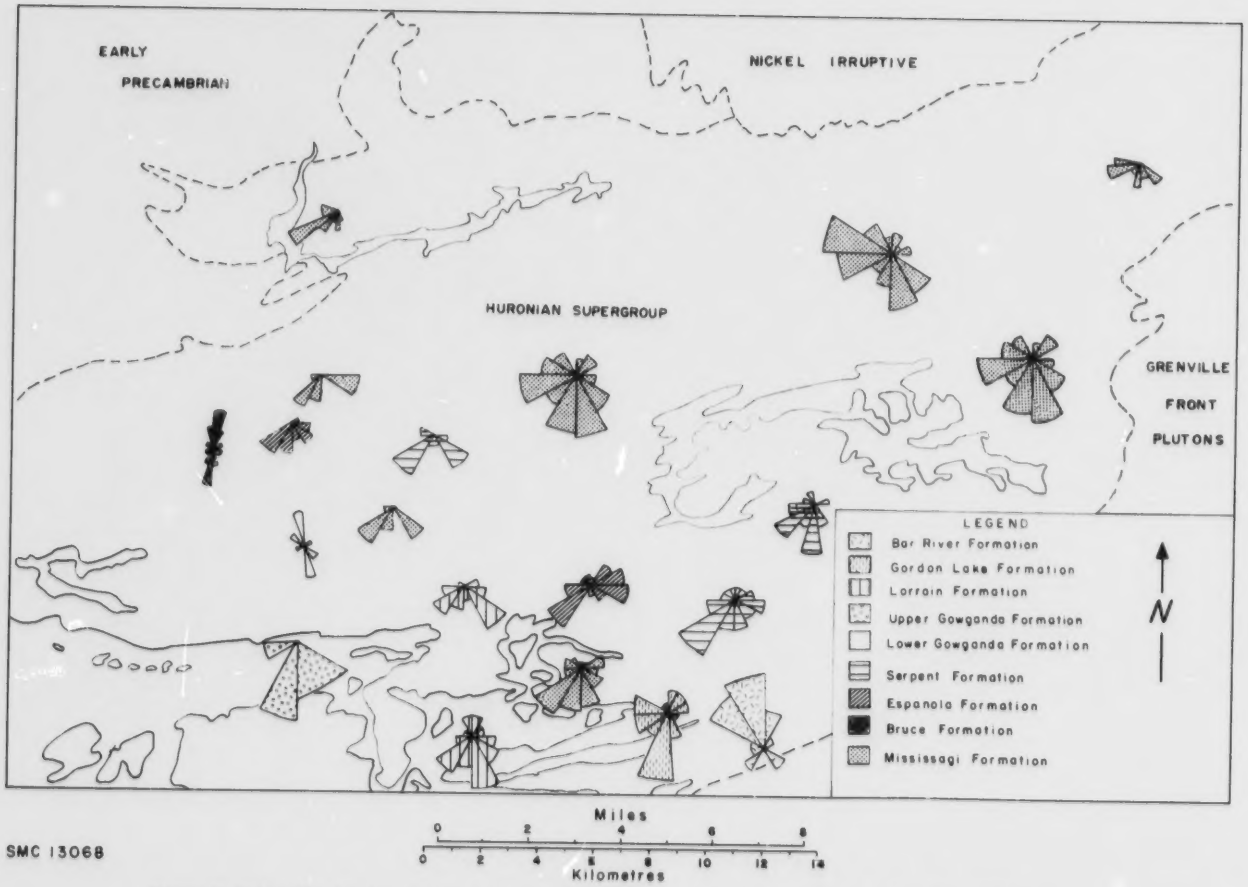

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Figure 3–Generalized paleocurrent pattern of the Huronian Supergroup in the Sudbury-Espanola area.

a middle sequence of submature to mature hematitic and aluminous sandstone, and an upper sequence of very mature orthoquartzite. Crossbeds are common in the lower units, ripples in the upper. The appearance of hematite and the replacement of feldspars by aluminous minerals (kaolinite, or the metamorphic minerals muscovite, pyrophyllite, kyanite, and andalusite) takes place at about the same stratigraphic level and marks probably a change from rigorous to tropical climatic conditions.

The Gordon Lake Formation consists of about 2,000 feet (600 m) of fine-grained, thin-bedded, green, buff, and purple siltstone, argillite and sandstone which contain abundant intraformational breccias, ripples, desiccation cracks, and flame structures. The Bar River Formation includes some 3,000 feet (900 m) of crossbedded and ripple marked orthoquartzite and siltstone, some beds of which contain abundant hematite.

The paleocurrent data available indicate that the Huronian sedimentary rocks were deposited by southflowing currents and that the paleoslope remained relatively constant throughout deposition of the sequence (Figure 3). Studies by Palonen (1971), Card (1969), and others indicate that many of the sandstone formations have polymodal paleocurrent patterns that can be interpreted as a result of the interaction of south-flowing depositional currents with longshore (mainly west flowing) and onshore (northward currents in a shallow marine environment.

In summary, the Huronian rocks record rapid deposition by facies migration of mainly immature clastic sediments that were derived from a dominantly felsic plutonic terrane to the north, and were deposited in the form of a southeastward-thickening wedge on the southern flank of the Superior Province craton. There is a general upward increase in mineralogical and textural maturity within the sequence as a whole.

It has been postulated that recurrent glaciation played a major role in the development of the Huronian sequence (Coleman 1926; Casshyap 1969; Roscoe 1969; Young 1970, 1973; Lindsey 1971). According to this model, the conglomeratic rocks represent the direct deposits of several major continental-marine glacial episodes, the pelitic rocks are post-glacial transgressive deposits, and the sandstones regressive, prograding fluvial deposits. Much of the Huronian sequence has been described as the product of fluvial deposition in an alluvial environment (Frarey and Roscoe 1970), mainly on the basis of reported unimodal paleocurrent patterns in Huronian sandstones in the north (McDowell 1957), and on the postulated glacial origin of the conglomeratic rocks.

However, as Pettijohn (Pettijohn 1970) has pointed out, the Huronian sequence could also represent the deposits of a series of regressive marine cycles that rarely, if ever, became emergent surfaces of accumulation. Evidence for such a model includes:

(1) Lack of fining-upward cycles characteristic of fluvial deposits, and the presence of coarsening-upward cycles in several formations.
(2) The presence of polymodal paleocurrent patterns in many formations that indicate reworking by longshore and onshore current systems in a marine, littoral-neritic environment.
(3) Attributes of some of the rocks; especially the mature sandstones of the Lorrain and Bar River Formations that are notably different in sorting, rounding, and composition from typical fluvial sands. The presence of abundant carbonate in the Espanola Formation may also indicate a marine origin.

(4) Evidence for a relatively deep-water, turbidite origin for several units, notably some units in the McKim, Pecors, and Gowganda Formations.

(5) Other evidence indicating a possible general increase in the depth of water and in the amount of reworking from north to south, includes the following: the overall southeastward thickening of the Huronian Supergroup, especially of the turbidite units, variations in lithology and paleocurrent patterns in the sandstones, and the bedded nature of conglomeratic units such as those in the Gowganda Formation in the south of the report-area.

According to the postulated marine model, sandstone units such as those in the Matinenda, Mississagi, Serpent, and Lower Lorrain Formations represent regressive facies deposited in relatively shallow, turbulent waters, probably in a deltaic-tidal flat environment (see Figures 1 and 3). The mature Upper Lorrain Formation and the Bar River Formation represent marine littoral or neritic deposits. Siltstone-greywacke units such as those in the McKim and Pecors Formations represent transgressive facies deposited under relatively deep-water conditions by turbidity currents. The Espanola Formation probably represents deposition in an agitated, shallow-water, marine environment; and the Gordon Lake Formation represents deposition in a quiescent, shallow-water environment in which only very fine terrigenous material was contributed.

Evidence for a glacial origin for conglomeratic rocks in the Ramsay Lake, Bruce, and Gowganda Formations includes the extensive sheet-like form, tilloid fabric, "drop stones", and evidence of long-distance transport of large rock fragments, and a regional preferred orientation of clasts indicative of transport by a high-density medium. However, it is possible that the Huronian conglomerates represent the deposits of extensive debris flows which occurred in a marine environment. The characteristics of such deposits are described by Dzulynski *et al.* (1959), Walker (1970), and others. The deposits are typically thick-bedded or massive, ungraded muddy sandstones with large, unsupported, oriented rock fragments which are typically associated with turbidites. Many are cleaner than "normal" turbidite greywacke, probably owing to the incorporation of relatively mature sands. Fisher (1971) describes debris flows as high-density fluids with a high concentration of coarse solids which flow in a laminar, rather than a turbulent, fashion. Debris flows because of their flow characteristics, can override and be deposited on easily eroded, unconsolidated, fine-grained sediments with little or no evidence of erosion. Rock fragments deposited by such flows may deform the underlying bedded sediments thus duplicating features displayed by ice-rafted "drop stones". Consequently, deposition by debris flows could account for the features displayed by the Huronian conglomeratic rocks. Such a mechanism could also account for several features not adequately explained by a glacial model; notably the relatively high proportion of mature sands in the conglomerate matrices, and the association of conglomerates with turbidites and with rocks displaying evidence of large-scale slumping. According to the postulated model, the conglomeratic rocks represent rapid deposition by extensive debris flows triggered by a tectonic activity and a sudden increase in the paleoslope; probably the result of sporadic tectonic activity along major boundary faults.

The available petrographic and chemical data for the rocks of every formation of the Huronian Supergroup within the area covered by this report (see inset map, Chart A back pocket) are outlined in the text, with accompanying tables, and figures. Emphasis is placed on the major petrographic and chemical character-

istics of each formation and on changes in mineralogical and chemical parameters within the sequence. Unless otherwise stated, all chemical analyses and normative calculations were made by the Mineral Research Branch, Ontario Division of Mines.

The Huronian rocks have been variably recrystallized and regionally metamorphosed under conditions ranging from the low greenschist facies to the low amphibolite facies (Card 1964). The original sedimentary textures and mineralogy were preserved to variable degrees in the samples studied by the authors. Changes caused by metamorphism include replacement of original matrix materials, presumably silt and clay, by metamorphic phyllosilicate minerals, and modification of clastic textures and grain shape by recrystallization and deformation.

Some Huronian sandstones have a disrupted fabric, but unlike classical greywackes, contain a high proportion of quartz and have few or no rock fragments. Metamorphic and deformational destruction may account for this dearth of rock fragments, although this feature is probably attributable to the provenance being dominantly granitoid plutonic rocks. Disintegration of relatively coarse-grained felsic plutonic rocks yielded quartz and feldspar grains of sand size, not rock fragments.

The classification system used here is based on the relative proportions of sand-size quartz, feldspar, rock fragments, and the generally finer grained interstitial materials, which are mainly phyllosilicate minerals and silt-size quartz and feldspar. Petrographic modal analyses are plotted in the form of triangular diagrams. Rocks containing 30 percent or more interstitial matrix materials are termed greywacke, even though most of these rocks contain few or no recognisable rock fragments. Some rocks owe their high matrix content and disrupted fabric to metamorphic processes. There are relatively well sorted, texturally mature sandstones consisting almost wholly of quartz (orthoquartzite), or of quartz and feldspars (arkose). Most of the Huronian sandstones have compositions intermediate between the foregoing end-members, namely greywacke and orthoquartzite. These sandstones are immature to submature texturally, and mineralogically, and consist mainly of quartz, feldspars, and minor rock-fragment grains with 10 percent to 30 percent interstitial matrix. Protoquartzite, as described in this report, is a light-coloured, generally submature, moderately well sorted sandstone with about 10 percent to 20 percent interstitial matrix. Subgreywacke is a dark-coloured, generally immature, poorly sorted sandstone containing 20 percent to 30 percent interstitial matrix.

Gabbro-Anorthosite Intrusions

Layered, sill-like or lopolithic mafic intrusions varying in thickness from less than 100 feet (30 m) to several thousand feet (900 m) occur at or near the base of the Huronian sequence in Denison, Drury, Baldwin, Shakespeare, Dunlop, Gough and Shibananing Townships, and they intrude Early Precambrian basement rocks (see inset map Chart A back pocket). Generally, the intrusions occur at the base of Huronian metavolcanic sequences, although locally they intrude Huronian metasediments.

Magmatic layering is prevalent in the intrusions, and the layers, ranging in thickness from about 2 feet (0.6 m) to several hundred feet (120 m), are defined

by variations in composition, grain size, and texture. Tabular plagioclase crystals show a preferred orientation in some layers. Other layers have a graded appearance caused by an upward increase in the proportion of plagioclase to the other minerals present. The attitude of the layering in the large intrusion in Dunlop Township is generally conformable to the contacts of the body.

The close spatial relationship between the Gabbro-Anorthosite Intrusions and the Huronian metavolcanics, and the chemical similarities between these two rock groups are discussed in succeeding sections of this report. Such factors indicate a genetic relationship between the Gabbro-Anorthosite Intrusions and the Huronian metavolcanics.

Petrography

The intrusions consist mainly of metamorphosed gabbro, anorthositic gabbro, and gabbroic anorthosite with minor, felsic (trondhjemitic, syenitic) segregations. The mafic rocks are coarse-grained, or very coarse grained, and exhibit equigranular, porphyritic, glomeroporphyritic, and pegmatitic textures.

The gabbroic and anorthositic rocks are composed essentially of variable proportions of plagioclase and femic minerals with minor amounts of quartz, granophyre, biotite, chlorite, muscovite, epidote, iron-titanium oxides, and sphene (Table 1). The plagioclase, probably originally a calcic variety (labradorite-bytownite) is extensively saussuritized. The femic minerals, blue-green hornblende and actinolite, are probably secondary after primary pyroxenes. Partly altered augite is present in some of the rocks studied.

The felsic segregations consist mainly of albite with minor quartz, potassium feldspar, amphiboles, micas, chlorite, epidote, sphene, and iron-titanium oxides (Table 1).

Chemistry

Chemical analyses and normative compositions of typical rocks of the Gabbro-Anorthosite Intrusions are given in Table 1. Various compositional parameters are plotted, along with those for Huronian volcanic rocks, (Figures 4a and 4b). These plots show that most of the gabbro-anorthosite rocks are similar in composition to the Huronian volcanic rocks, and are subalkaline and tholeiitic. In Figure 4a, (weight percent SiO_2 versus weight percent $Na_2O + K_2O$), the gabbroic and anorthositic rocks are closely grouped with the mafic metavolcanics; a trondhjemite falls within the alkaline field near the line dividing alkaline from subalkaline rocks. In Figure 4b, (weight percent Al_2O_3 versus normative plagioclase composition), the gabbroic rocks are grouped with the mafic metavolcanics in the tholeiitic field; anorthositic rocks and trondhjemite, which are strongly enriched in plagioclase, fall in the calc-alkaline field.

Table 1 CHEMICAL AND MODAL ANALYSES OF ROCKS OF GABBRO-ANORTHOSITE PLUTONS; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

	Chemical Analyses, Major Components in Weight Percent					
	1	2	3	4	5	6
SiO_2	52.00	51.80	51.40	55.40	64.30	48.76
Al_2O_3	14.40	18.80	16.80	22.30	17.80	23.59
Fe_2O_3	1.22	1.43	2.74	1.98	0.06	4.26
FeO	7.23	5.63	8.41	3.18	1.67	3.24
MgO	8.60	6.90	3.74	2.11	0.80	3.78
CaO	10.70	11.00	10.60	9.90	3.34	11.78
Na_2O	2.62	1.64	2.13	3.24	9.23	2.81
K_2O	0.39	0.43	0.89	0.64	0.79	0.49
H_2O^+	1.56	1.69	1.21	0.69	0.41	1.32
H_2O^-	0.07	0.08	0.08	0.06	0.14	...
CO_2	0.26	0.20	0.26	0.25	2.36	0.08
TiO_2	0.36	0.19	1.37	0.55	0.23	0.09
P_2O_5	0.04	0.02	0.07	0.02	0.05	0.06
S	0.01	0.01	0.05	0.01	0.01	...
MnO	0.18	0.12	0.18	0.08	0.06	0.07
Total	99.64	99.94	99.93	100.41	101.25	100.33
S.G.	2.98	2.83	2.97	2.85	2.57	2.91
	Trace Elements in PPM					
Ba	...	150	200	250	...	...
Co	40	40	50	16	6	...
Cr	250	100	40	80	10	...
Cu	30	30	150	40	8	...
Ga	15	15	20	30	10	...
Ni	130	230	80	60	20	...
Pb	10	10	10	10	10	...
Sc	40	20	25	20	...	...
Sr	300	300	250	300	250	...
V	100	100	400	200	20	...
Y	...	20	20	20	...	...
Zn	70	50	100	40	20	...
Zr	30	50	40	40	50	...
Be	...	...	...	...	3	...

Notes

(1) Anorthositic metagabbro, Baldwin Township.
(2) Pyroxene gabbro (partly altered), Shakespeare Township.
(3) Anorthositic metagabbro, Shakespeare Township.
(4) Gabbroic anorthosite, Shakespeare Township.
(5) Syenite (albitite), Baldwin Township.
(6) Gabbroic anorthosite, Drury Township.

Table 1—continued

Modal Analyses in Volume Percent

	1	2	3	4	5	6	7	8	9
Plagioclase	41.0	23.6	56	68	81.4	8	22	51	12
Amphibole	34.8	60.0	40	15	...	26	28	28	49
Pyroxene	3.1	...	...	...	...	...	...	...	...
Quartz	12.5	...	1	3	11.7	...	6	...	...
Granophyre		2.7				...	...	...	...
Biotite		7.8	2	9		5.1	...	...	...
Chlorite							8	x	3
Muscovite	...	...	...				...	x	11
Epidote	x	...					31	16	24
Sphene	8.6	5.9	1	5	4.3	...	...	...	...
Iron-Titanium Oxides					2.6	1	1	...	1
Carbonate	...	...	...	...	...	11	4	...	...
Zircon	...	...	...	...	...	...	...	...	...
Apatite	...	...	...	...	...	...	...	...	...
Calcite	x	...	...	...	...	...	...	...	...
Plagioclase Composition	$An_{60\pm5}$	Labradorite	...	...	Albite	...	...	...	...

Notes

(1) Partly altered pyroxene gabbro, Shakespeare Township.
(2) Mafic metagabbro, Shakespeare Township.
(3) Metagabbro (average of 3), Shakespeare and Dunlop Townships.
(4) Anorthositic gabbro and gabbroic anorthosite (average of 4).
(5) Albitite segregation, Shakespeare Township and Dunlop Township.
(6) Amphibolite, Drury Township.
(7) Metagabbro, Drury Township.
(8) Anorthositic gabbro, Drury Township.
(9) Porphyritic amphibolite dike (average of 2), Drury Township.

Abbreviations

S.G. – Specific Gravity
x – Trace amounts detected
... – Not detected

Elliot Lake Group

ELSIE MOUNTAIN FORMATION

Distribution and Lithology

Mafic metavolcanics of the Elsie Mountain Formation, which represent the basal part of the Huronian sequence in the Sudbury area, are exposed in a belt that extends east and northeast from Drury Township to and beyond McKim Township south of the Sudbury Nickel Irruptive. The formation is well exposed in the area south of the Murray Mine in McKim Township where it forms a series of hills. One of the hills is known locally as "Elsie Mountain". The Elsie Mountain Formation is intruded by the Nickel Irruptive, the Creighton and Murray Felsic Plutons, and by Gabbro-Anorthosite Intrusions. The Elsie Mountain Formation, as defined herein, corresponds approximately to the unit termed "Lower Stobie Series" by Cooke (1946) and is part of Coleman's (1914) "Sudbury Series".

The Elsie Mountain Formation, which has a maximum preserved thickness of about 3,300 feet (1 000 m) in the study area, consists mainly of metabasalt with minor amounts of intercalated pelitic metasediments and mafic tuffaceous rocks. Mafic intrusive rocks are probably also present, but metamorphic recrystallization and structural deformation have rendered distinction of extrusive and intrusive phases difficult.

Mafic flows vary in thickness from 75 to 300 feet (23 to 90 m). Flow thicknesses decrease upward in the sequence and westward in the formation. The rocks are medium to coarse grained, and some flows display a gradation in grain size from medium grained in the upper parts to coarse grained in the central and lower portions. Many flows in the lower part of the Elsie Mountain Formation are porphyritic, with large phenocrysts (up to 2 inches; 5 cm) of plagioclase. Some flows in the middle and upper parts of the formation show pillows and amygdaloidal tops. The amygdules are composed of quartz, chlorite, and amphiboles, and are up to 1 cm in diameter. The pillows, which are often tectonically deformed, are up to 2½ feet (0.75 m) in maximum dimension and some are outlined by thin, dark green fine-grained selvages.

A zone of "pillow breccia" or incipient pillows that occurs in east-central Graham Township consists of subrounded, pillow-like fragments 2 to 4 inches (5 to 10 cm) in diameter surrounded by fine-grained chilled margins or selvages in a medium-grained mafic tuffaceous matrix.

Pelitic and quartz-rich metasediments intercalated with the mafic flows form laterally persistent units 30 to 60 feet (9 to 18 m) thick. These metasediments are well bedded, the bedding averaging about 1 foot (0.3 m) in thickness, and most are notably rich in aluminous minerals such as staurolite, garnet, and white micas.

Petrography and Chemistry

The metabasalts of the Elsie Mountain Formation are dark green to black, medium- to coarse-grained rocks which display coarse gabbroic and fine, foliated textures. The metabasalts consist mainly of amphiboles (hornblende, actinolite), plagioclase (An_{20} to An_{40}), quartz, and chlorite with lesser amounts of mica (mainly biotite), epidote or clinozoisite, garnet, apatite, sphene, sericite, pyrite, pyrrhotite, magnetite, and ilmenite. These minerals represent the products of metamorphic recrystallization, under conditions corresponding to the amphibolite and greenschist facies of regional metamorphism. The original igneous mineral assemblage probably consisted mainly of calcic plagioclase and pyroxene. Approximate modal analyses of typical specimens are given in Table 2.

Some amygdules consist of a single quartz grain showing intense undulose extinction, others consist of a granoblastic mosaic of fine-grained quartz with minor amounts of blue, iron-rich chlorite, and a few are distinctly zoned with chlorite and amphiboles concentrated about the outer margin or forming a clot in the central portion. Veinlets and segregations of quartz and carbonate are present in some of the specimens examined.

Chemical data, including major oxide and trace element analyses of the rocks of the Elsie Mountain Formation are presented in Table 2. Normative calculations for the metavolcanics were made by computer, and from these calculations, petrographic indices were calculated, and plotted according to methods outlined by Irvine and Baragar (1971). The various plots, presented in Figure 4, show that the metavolcanic rocks of the Elsie Mountain Formation are subalkaline (Figure 4a), tholeiitic (Figure 4b and 4e), and are average to slightly potassic (Figure 4d) basalts (Figure 4c). Figure 5, showing variations in petrographic indices with stratigraphic height for the Elsie Mountain, Stobie, and Copper Cliff Formations, reveals relatively little variation in these indices within the Elsie Mountain Formation. These variations in petrographic indices in the sequence as a whole do suggest a relatively continuous differentiation into mafic and felsic end members.

Variations in the major oxides of the metavolcanics and associated metasediments of the Elsie Mountain, Stobie, Copper Cliff and McKim Formations with increasing stratigraphic height are shown in Figure 6. Again, there is relatively little variation within the Elsie Mountain Formation; but upward in the sequence as a whole, discernible increases in SiO_2 and K_2O, and decreases in Al_2O_3, CaO, MgO, TiO_2, Fe_2O_3, and FeO occur. Most of the intercalated metasediments have chemical trends similar to those displayed by the metavolcanics. The chemical trends indicate that the sedimentary rocks were probably derived from the metavolcanics.

Figure 7 shows the variations in trace elements with stratigraphic height for the metavolcanics and metasediments of the sequence. In the metavolcanics, most trace elements increase upward in the Elsie Mountain and Stobie Formations, and then decrease in the Copper Cliff Formation. Generally, there is an inverse relationship between the trace element content of the metavolcanics and the intercalated metasediments. For example, where Cr and Ni concentrations in the Stobie Formation metasediments are low, Cr and Ni concentrations are relatively high in the Stobie Formation metavolcanics.

Table 2 CHEMICAL AND MODAL ANALYSES OF ROCKS OF THE ELSIE MOUNTAIN FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

	1	2	3	4	5	6	7
	Chemical Analyses, Major Components in Weight Percent						
SiO_2	51.20	49.00	57.38	59.40	59.30	61.48	54.40
Al_2O_3	14.10	19.40	25.33	23.10	21.80	21.77	16.30
Fe_2O_3	0.70	1.50	1.13	1.10	0.46	2.64	2.77
FeO	11.50	7.92	4.86	4.19	5.42	4.10	7.89
MgO	6.22	4.32	2.48	1.58	2.05	2.74	4.83
CaO	10.50	12.40	0.34	0.59	0.90	1.39	2.19
Na_2O	1.97	1.37	2.08	1.30	1.56	1.32	3.04
K_2O	0.61	0.47	2.01	4.59	4.13	2.20	1.34
H_2O^+	1.04	1.51	3.60	2.17	2.52	1.23	3.48
H_2O^-	0.09	0.11	0.07	0.55	0.13	0.07	0.03
CO_2	0.14	0.12	0.64	1.06	0.08	0.53	0.05
TiO_2	1.10	1.05	1.00	1.17	1.25	0.88	1.21
P_2O_5	0.08	0.11	0.11	0.10	0.10	0.12	0.14
MnO	0.24	0.18	0.05	0.04	0.06	0.06	0.13
FeS_2	0.01	0.01	...	...	...	...	1.36
Total	99.50	99.47	101.08	100.94	99.76	100.53	99.16
S.G.	3.04	3.08	2.83	2.72	2.78	2.88	2.80
	Trace Elements in PPM						
Ba	150	...	600	1200	1000	900	400
Cr	150	70	250	300	200	150	200
Co	50	40	20	20	20	20	10
Cu	20	80	10	100	30	300	100
Ga	30	30	...	...	...	...	...
Ni	130	70	80	60	80	80	80
Pb	10	10	20	15	10	20	15
Sc	30	20	20	20	30	10	150
Sr	130	150	200	150	100	200	
V	200	130	150	250	200	150	250
Y	15	20	10	10	20	10	10
Zr	60	60	80	150	150	150	150
Zn	130	110	...	...	60	...	...

Notes

1. Metabasalt, Elsie Mountain Formation, Waters Township.
2. Porphyritic metabasalt, Elsie Mountain Formation, Graham Township.
3. Staurolite metapelite, Elsie Mountain Formation, Waters Township.
4. Staurolite metapelite, Elsie Mountain Formation, Graham Township.
5. Argillaceous metapelite, Elsie Mountain Formation, Graham Township.
6. Staurolite-biotite metapelite, Elsie Mountain Formation, Waters Township.
7. Metapelite, Elsie Mountain Formation, Graham Township.

Abbreviations

S.G. – Specific Gravity

... – Not detected

Table 2–continued

Modal Analyses in Percent

	1	2	3	4
Hornblende	55	46	72	
Plagioclase	27	32	14	7.5
Quartz	6	6	14	10
Chlorite	5	9	x	7.5
Biotite			x	...
Epidote	2	2	1	...
Carbonate			x	...
Sericite	x	x	x	77.5
Apatite	x	x'	...	...
Iron oxide	5	5	2	2.5
Sulphide				
Sphene	x	x		
Plagioclase Composition	n.d.	An_{33}	An_{30}	n.d.

Notes

1. Metabasalt, Waters Township.
2. Porphyritic metabasalt, Graham Township.
3. Average of 3 metabasalts, Graham Township.
4. Aluminous (muscovitic) metapelite, Graham Township.

Abbreviations

x – Trace amounts only
n.d. – Not determined
S.G. – Specific Gravity
... – Not detected

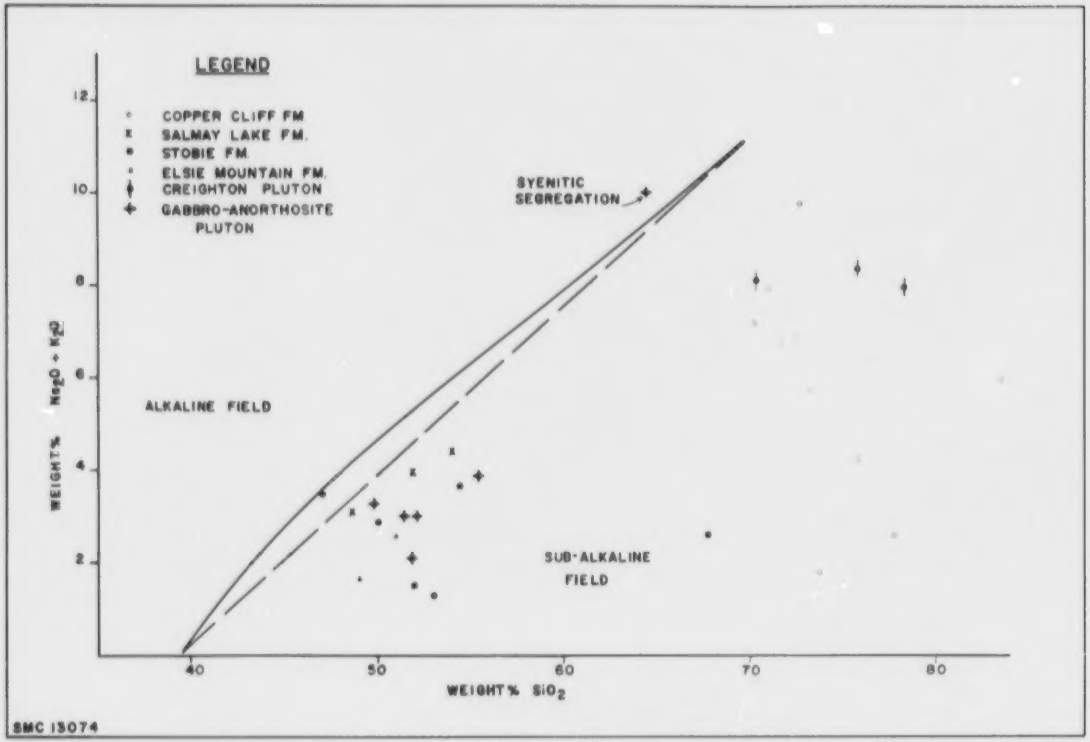

Figure 4a–Weight percent SiO_2 versus weight percent $Na_2O + K_2O$ for the metavolcanics of the Elsie Mountain, Stobie, and Copper Cliff Formations, and of the Creighton and gabbro-anorthosite plutons.

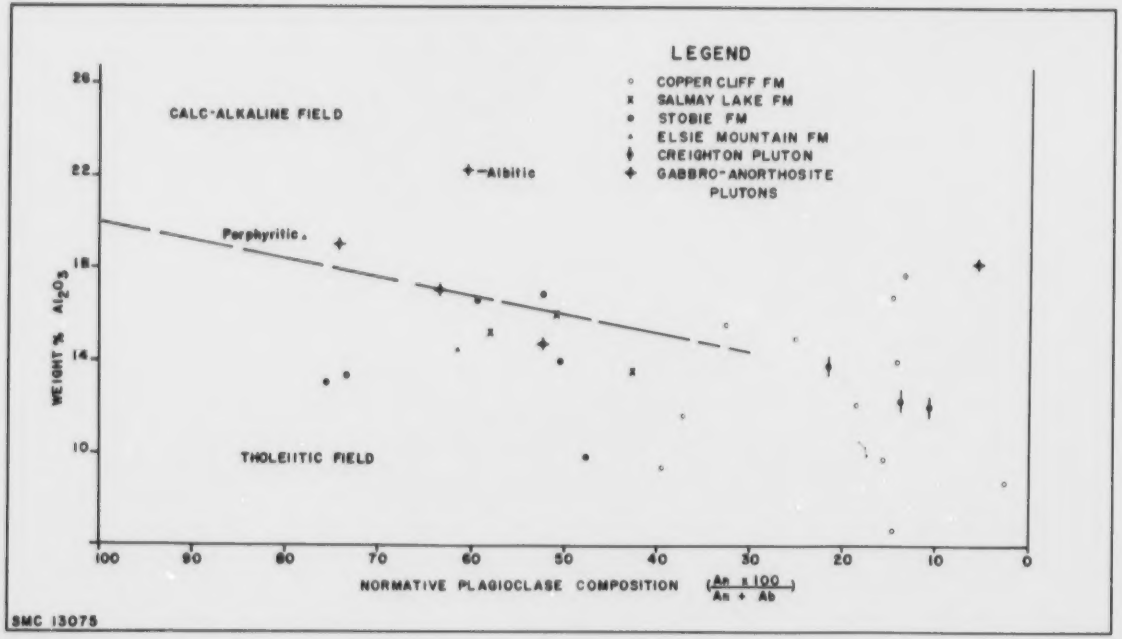

Figure 4b–Weight percent Al_2O_3 versus normative plagioclase composition for the metavolcanics of the Elsie Mountain, Stobie, and Copper Cliff Formations and the Creighton, and gabbro-anorthosite plutons.

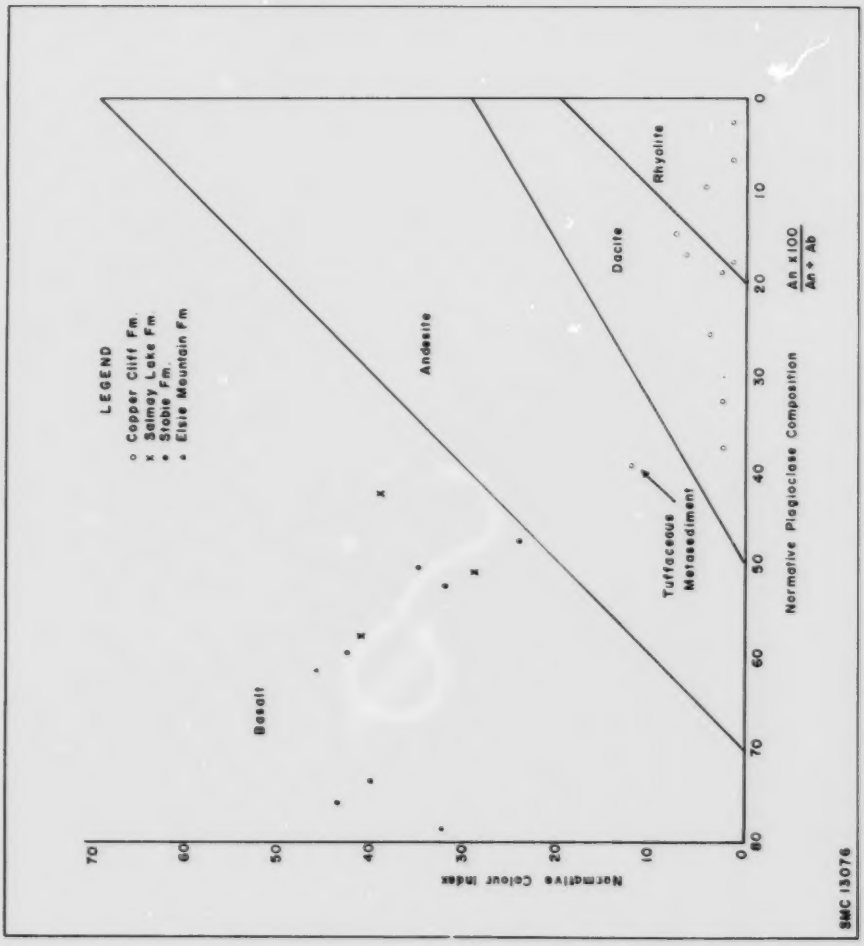

Figure 4c–Normative colour index versus normative plagioclase composition for the metavolcanics of the Elsie Mountain, Salmay Lake, Stobie, and Copper Cliff Formations.

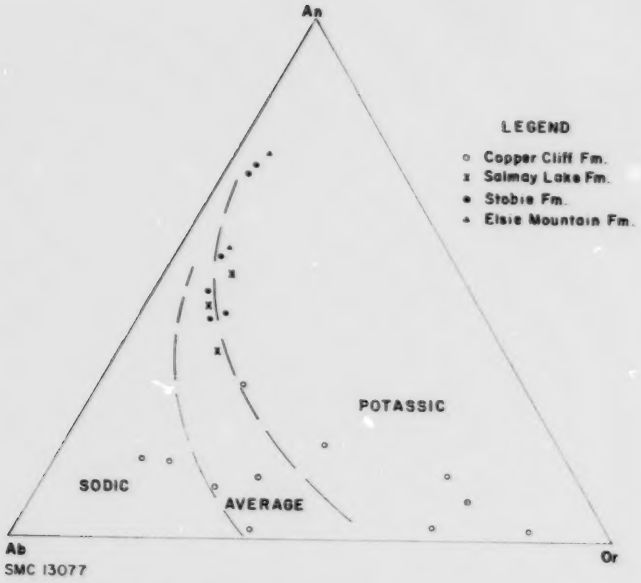

Figure 4d–An—Ab—Or plots for the metavolcanics of the Elsie Mountain, Salmay Lake, Stobie, and Copper Cliff Formations.

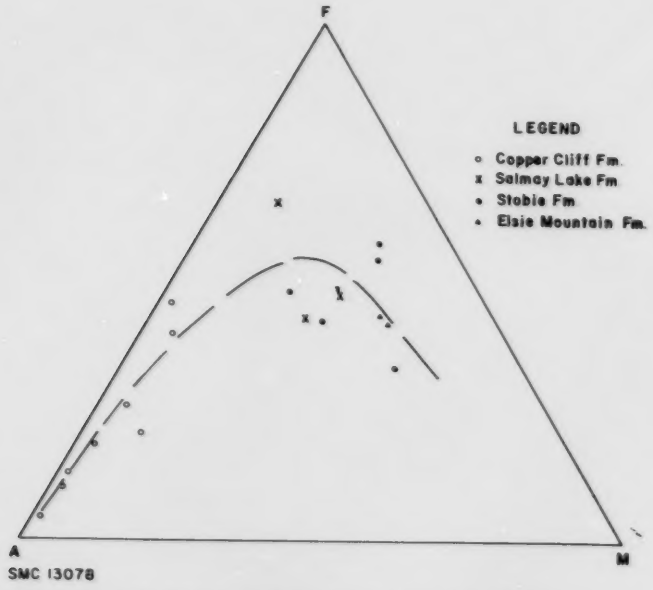

Figure 4e–AFM diagram for the metavolcanics of the Elsie Mountain, Salmay Lake, Stobie, and Copper Cliff Formations.

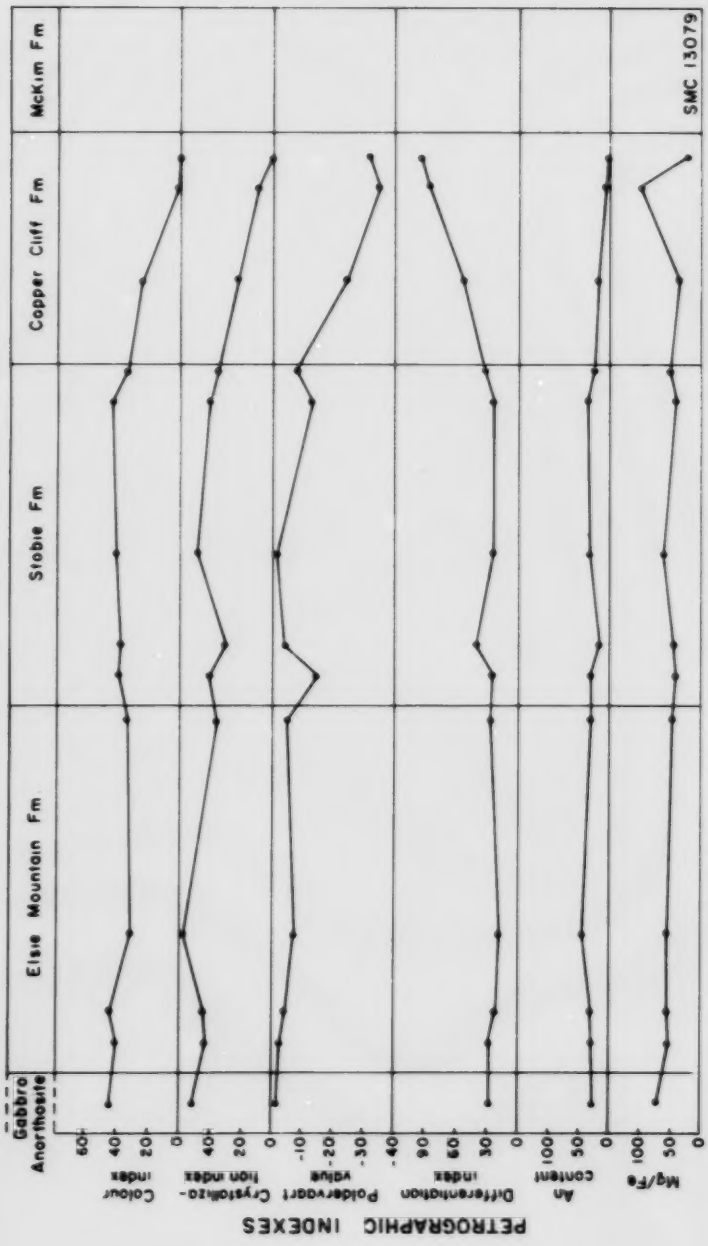

Figure 5–Variation of petrographic indices with stratigraphic height in metavolcanics of the Elsie Mountain, Stobie, and Copper Cliff Formations in the Sudbury area.

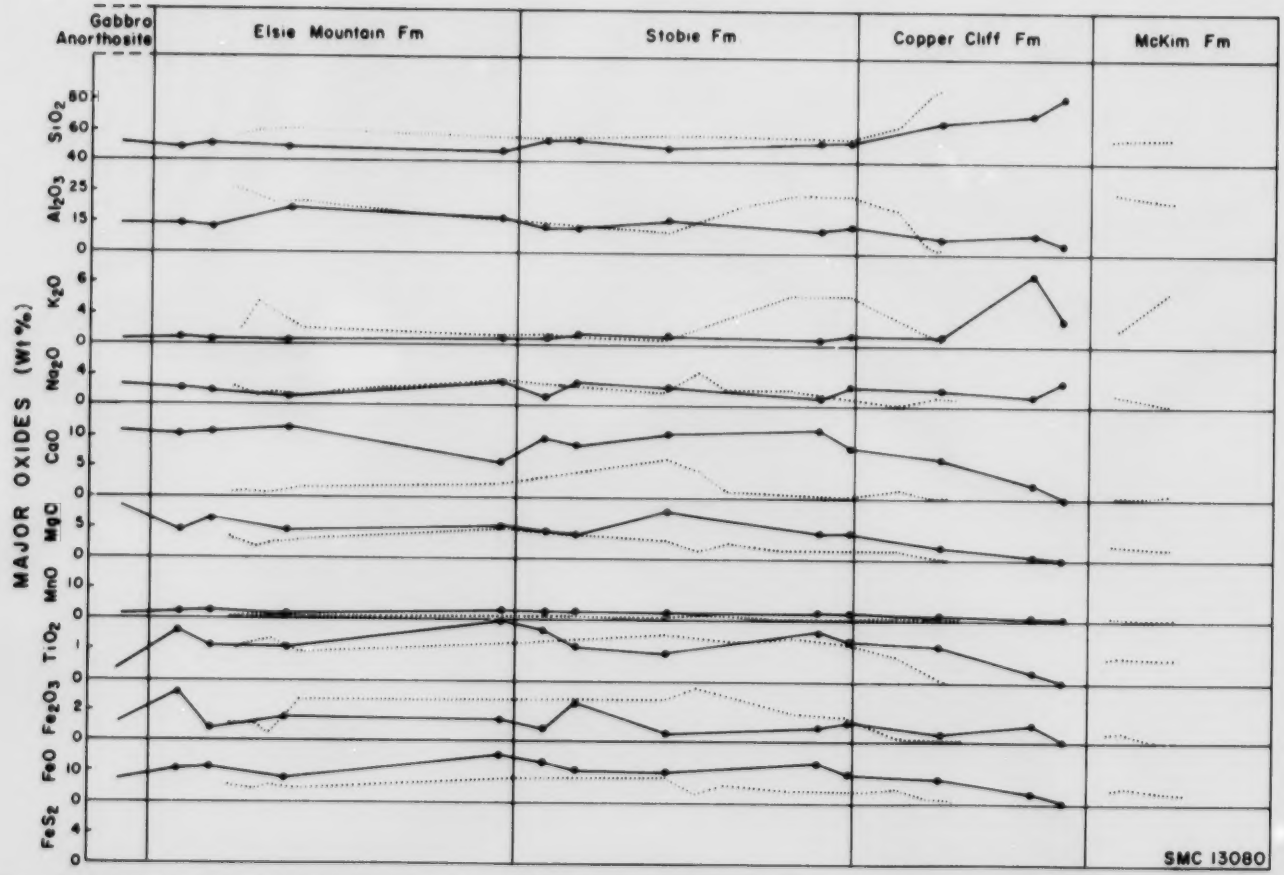

Figure 6–Variation in major oxides with stratigraphic height in rocks of the Elsie Mountain, Stobie, and Copper Cliff Formations. The solid lines represent variations in metavolcanics; the dotted lines represent variations in intercalated metasediments.

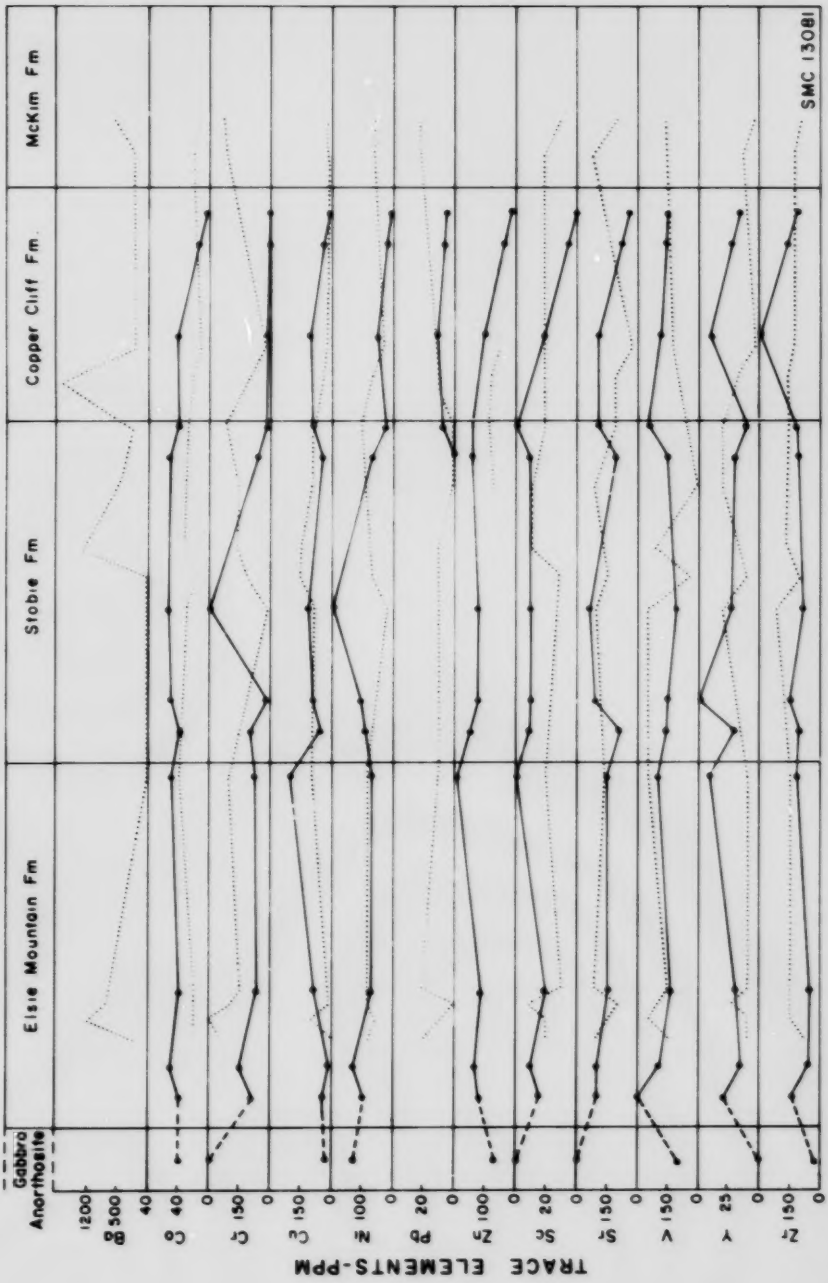

Figure 7–Variation in trace elements with stratigraphic height in rocks of the Elsie Mountain, Stobie, and Copper Cliff Formations. The solid lines represent variations in metavolcanics, the dotted lines represent variations in intercalated metasediments and tuffaceous units.

STOBIE FORMATION

Distribution and Lithology

Rocks of the Stobie Formation, which include mafic metavolcanic flows (and mafic intrusions?), tuffs, and metasediments, overlie the Elsie Mountain Formation in an area south of the Sudbury Nickel Irruptive that extends from Hyman Township in the west, to beyond McKim Township in the east. The contact between the Stobie and Elsie Mountain Formations is conformable and gradational, and in the field was arbitrarily placed where sulphide-bearing (generally more than 3 percent sulphide minerals) pelitic metasedimentary intercalations appear in the section. To the west, rocks of the Stobie Formation are intercalated with greywacke and quartz-feldspar sandstone of the McKim and Matinenda Formations. The Stobie Formation is well exposed in the central part of Graham Township. The authors suggest that the type area be established there.

The Stobie Formation has an average thickness of about 2,800 feet (850 m) in Graham, Waters, and McKim Townships, and is possibly as much as 5,000 feet (1 500 m) thick in Denison and Drury Townships, but thins rapidly westward and is absent west of the Agnew Lake Mine in central Hyman Township. The proportion of metavolcanic flows to metasediments decreases upward in the formation from about 80 percent in the lower part to less than 5 percent in the upper portions. Thicknesses of individual flows also decrease upward from about 75 feet (23 m) to 5 feet (1.5 m).

Cyclic repetitions of metavolcanics and metasediments occur throughout the Stobie Formation. A typical cycle consists of a metabasalt flow overlain by a sulphide-bearing siltstone or greywacke unit commonly 1 to 10 feet (0.3 to 3 m) thick, that is in turn overlain by relatively sulphide-free pelite, and quartz-feldspar sandstone. Commonly the contact between the flows and overlying metasediments has a disrupted or stirred appearance, a feature termed "stirred tops" in this report. Generally these stirred tops show crude layering and consist of metavolcanic and metasedimentary rock fragments in a matrix of amphibole, quartz, feldspar, chlorite and biotite, with some epidote, carbonate, iron oxide minerals, and sulphide minerals. Field and petrographic studies suggest that the stirred tops are the result of extrusion of flows into a basin experiencing rapid sedimentation with consequent mixing of volcanic and sedimentary materials at the flow-sediment interface. Alternatively, the stirred tops may represent tuffaceous material.

Breccia formed by the autobrecciation of the solidified crust of metabasalt flows is present in the Stobie Formation. Lahar-type breccia, consisting of 3- to 6-inch (7.5 to 15.0 cm), medium-grained, angular fragments of metabasalt in a fine-grained mafic matrix occurs in the lower part of the Stobie Formation in east-central Denison Township.

Petrography and Chemistry

The metavolcanics of the Stobie Formation are similar to those of the underlying Elsie Mountain Formation, consisting of massive and foliated fine- to coarse-grained metabasalt. Amygdules are common, and pillows are present. The

Table 3 | CHEMICAL AND MODAL ANALYSES OF ROCKS OF THE STOBIE FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

Chemical Analyses, Major Components in Weight Percent

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	47.00	54.20	53.90	49.90	53.00	54.00	67.60	57.40	64.00	58.40	58.40	56.60	56.10
Al_2O_3	16.60	13.00	13.40	15.90	12.80	13.70	9.75	23.80	20.00	12.40	15.70	19.80	24.50
Fe_2O_3	1.27	0.73	2.55	0.46	0.93	1.53	0.58	1.60	0.29	2.92	3.71	3.17	1.95
FeO	14.70	12.20	10.20	9.45	12.90	9.28	7.85	3.89	4.32	8.39	2.97	5.42	3.96
MgO	5.10	4.29	4.31	7.81	4.05	4.33	2.00	1.58	1.58	3.10	1.37	2.50	1.42
CaO	5.59	9.55	8.55	10.30	11.00	8.27	6.33	0.38	1.15	6.53	4.77	1.18	0.68
Na_2O	2.73	1.20	2.91	2.37	1.06	2.51	1.94	1.43	2.19	1.85	4.25	2.07	2.20
K_2O	0.80	0.27	1.49	0.53	0.24	1.14	0.66	5.43	3.21	1.04	1.98	3.69	5.29
H_2O^+	2.18	1.05	1.45	1.55	0.92	0.91	0.59	1.72	1.29	1.83	0.23	3.02	1.59
H_2O^-	0.03	0.04	0.08	0.07	0.07	0.32	0.07	0.11	0.03	0.12	0.30	0.23	0.10
CO_2	0.36	0.21	0.33	0.17	0.45	1.11	0.38	0.01	0.21	0.10	0.15	....	0.10
TiO_2	2.02	1.56	1.03	0.84	1.59	1.35	1.11	1.19	0.82	1.52	1.40	1.27	1.39
P_2O_5	0.15	0.11	0.05	0.09	0.17	0.18	0.14	0.01	0.87	0.17	0.05	0.12	0.10
MnO	0.26	0.23	0.29	0.19	0.22	0.18	0.16	0.03	0.05	0.15	0.15	0.06	0.03
FeS_2	1.77	0.11	0.01	0.01	0.03	0.13	0.22	0.94	3.80	1.63	3.92	1.85	0.95
Total	100.56	98.75	100.55	99.64	99.43	98.94	99.38	98.52	99.39	100.15	99.35	100.98	100.36
S.G.	2.96	3.08	2.93	2.98	3.12	2.92	2.91	2.72	2.74	2.94	2.75	2.82	2.76

Trace Elements in PPM

Ba	...	...	500	150	...	500	150	600	1500	400	300	1200	800
Cr	80	100	20	300	60	20	15	30	100	10	100	150	150
Co	50	40	50	50	50	40	40	10	20	30	20	30	30
Cu	200	40	90	110	50	100	100	20	40	100	150	150	90
Ga	40	30	20	15	40	...	20	20	30	20	60	70	90
Ni	70	90	100	200	70	20	50	30	70	15	30	15	10
Pb	10	10	10	10	10	15	15	15	15	30	10	30	30
Sc	40	30	30	30	30	40	20	20	20	200	150	150	200
Sr	150	80	20	250	100	200	200	100	100	250	50	200	...
V	200	150	150	120	150	250	200	50	150	30	10	15	30
Y	40	20	50	20	20	10	40	30	15	200	100	150	150
Zr	120	120	150	80	120	100	300	150	150	...	...	...	70
Zn	190	150	120	110	140	...	100	80	80	...	...	...	...

Table 8—continued

Notes

1. Metabasalt, Waters Township.
2. Metabasalt, Waters Township.
3. Amygdaloidal metabasalt, Graham Township.
4. Metabasalt, Denison Township.
5. Metabasalt, Denison Township.
6. Metabasalt, Graham Township.
7. Amygdaloidal metabasalt, Denison Township.
8. Sulphide-bearing argillite, Denison Township.
9. Sulphide-bearing siliceous argillite (tuffaceous?), Denison Township.
10. Sulphide-bearing metapelite, Graham Township.
11. Sulphide-bearing metapelite, Graham Township.
12. Sulphide-bearing metapelite, Graham Township.
13. Sulphide-bearing metapelite, Graham Township.

Abbreviations

S.G. – Specific Gravity

... – Not detected

Modal Analyses in Volume Percent

	1	2	3	4	5	6	7	8	9
Hornblende	14	51	45	45	30	50	24	9	8
Plagioclase	33	18	20	15	28	20	x	12	8
Quartz	8	9	10	15	16	1	35	40	50
Chlorite	35	13	12	14	6	8	3	8	5
Biotite					4	2	5	5	4
Epidote	1	3	4	3	5	10	x	x	2
Carbonate							x	2	4
Sericite	x	x	x	x	x	x	3	10	10
Apatite	x	...	x	x	x	...	...	...	...
Iron Oxides	9	6	5	8	8	1.5	7	7	8
Sulphides						x			
Sphene	x	x	x	x	x	0.5	...	...	...
Potassium Feldspar	...	...	...	...	...	...	x	...	x
Garnet	...	...	...	...	...	...	x	x	x
Plagioclase Composition	An_{24}	An_{40}	An_{30}	An_{40}	An_{26}	...	...	...	...

Notes

1. Metabasalt, Waters Township.
2. Metabasalt, Waters Township.
3. Amygdaloidal metabasalt, Graham Township.
4. Metabasalt, Denison Township.
5. Metabasalt, Graham Township.
6. Average of 3 metabasalts, Drury Township.
7. Sulphide-bearing metapelite, Graham Township.
8. Sulphide-bearing metapelite, Graham Township.
9. Sulphide-bearing metapelite, Graham Township.

Abbreviations

x – Not determined

... – Not detected

Stobie Formation metabasalts are petrographically similar to those of the Elsie Mountain Formation, consisting essentially of amphiboles and plagioclase, with lesser amounts of micas, chlorite, epidote, iron oxides, and sulphides (Table 3).

Metasediments in the Stobie Formation include siltstone, greywacke, quartz-feldspar sandstone, and conglomeratic sandstone. The siltstone and greywacke consist of quartz, muscovite, chlorite, amphibole, and biotite, and generally contain appreciable amounts of pyrite, pyrrhotite, magnetite, ilmenite, and chalcopyrite. The metasediments were probably derived from the volcanic rocks, and may be tuffaceous, in part similar to the "stirred tops" previously described. The quartz-feldspar sandstone and conglomeratic sandstone are relatively well-sorted rocks consisting mainly of quartz, feldspars, and white micas. These rocks were probably derived for the most part from the granitic rocks of the Superior Province to the north.

Sulphide-rich pelitic metasediments of the Stobie Formation contain up to about ten percent sulphide minerals, mainly pyrrhotite with lesser amounts of pyrite and chalcopyrite. These sulphide-rich units are general less than 10 feet (3 m) thick, but are persistent along strike for distances of several thousand feet, or in some cases, several miles (8 km). Zones of sulphide-rich units have been traced from Denison Township eastward to Graham Township, a distance of some 15 miles (25 km).

The sulphide minerals occur as disseminations, stratiform layers, and concentrations along joints and fracture surfaces. Studies by Innes (1972) show that the amount and types of sulphide minerals vary systematically within the flow-metasediment cycles described previously. Typically, the amount of sulphide minerals increases rapidly from the upper part of a flow into the "stirred top" portion, reaches a peak in the overlying pelitic metasediments, and then decreases toward the top of the metasedimentary unit, especially where quartz-feldspar sandstones are present (Figure 8). Disseminated pyrite, pyrrhotite, and chalcopyrite are present in nearly equal proportions in the "stirred top" portion. Pyrrhotite with minor chalcopyrite occurs as thin stratiform layers in the well-bedded sedimentary rocks immediately above the "stirred top" portion; disseminated pyrite with some pyrrhotite is present in the middle and upper parts of sulphide-rich units. Innes (1972) also noted petrographic evidence for sulphide-silicate and sulphide-oxide reactions. Possibly, metallic elements such as iron and copper were extracted from ferromagnesian minerals of the flows by H_2S-rich hydrothermal solutions. The resulting sulphide minerals were deposited in the overlying volcanigenic sedimentary rocks.

The volcanic rocks of the Stobie Formation are chemically similar to those of the Elsie Mountain Formation (see Table 3). Nevertheless, some of the Stobie volcanic rocks are slightly richer in alumina, plot near the line dividing the tholeiitic and calc-alkaline fields on the alumina-normative plagioclase diagram (see Figure 4b), and near the basalt-andesite line on the normative colour index-normative plagioclase diagram (see Figure 4c). Variations in petrographic indices, major oxides, and trace elements for the rocks of the Stobie Formation, shown in Figures 5, 6 and 7, have been discussed in the section "Elsie Mountain Formation, Petrography and Chemistry."

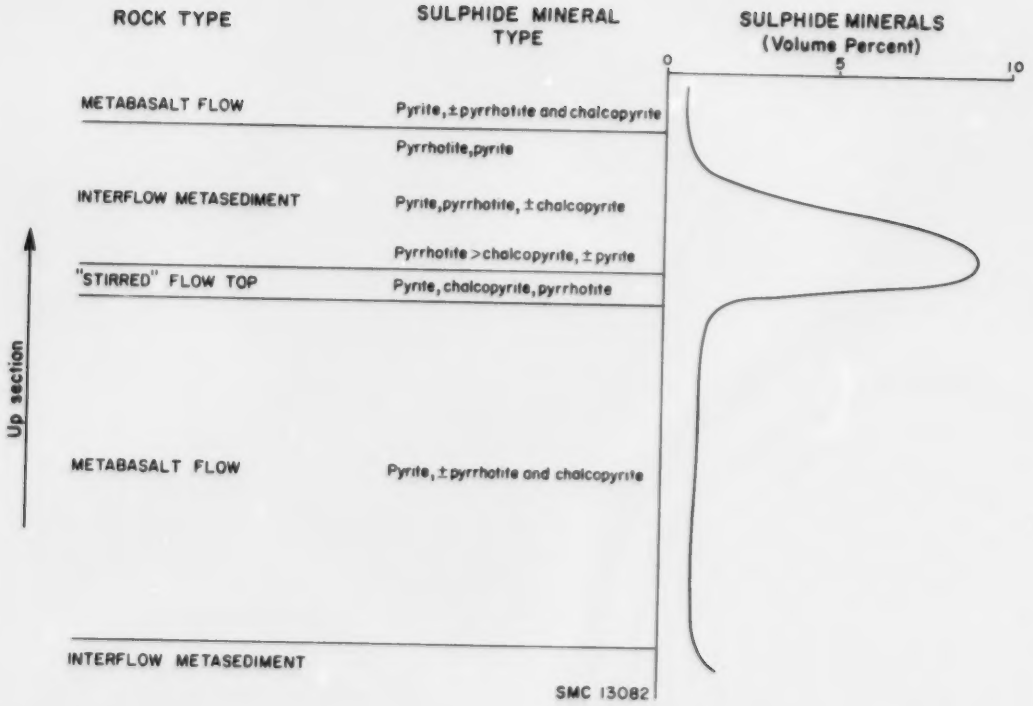

Figure 8–Distribution of sulphide minerals in a metavolcanic-metasedimentary cycle of the Stobie Formation.

COPPER CLIFF FORMATION

Distribution and Lithology

Felsic metavolcanics of the Copper Cliff Formation form a northeast-trending belt in Graham, Waters, and McKim Townships; they conformably overlie rocks of the Stobie Formation, and are conformably overlain by the McKim Formation. The Copper Cliff Formation has a maximum thickness of about 2,400 feet (730 m) and is exposed over a strike length of some 15 miles (25 km). The formation is well exposed throughout McKim and Waters Townships. The authors recommend that the type area for the Copper Cliff Formation be established in these townships. Also, several felsic hypabyssal intrusions (plug-like stocks and dikes) intrude rocks of the Elsie Mountain and Stobie Formations in Denison and Graham Townships. These intrusions are chemically and petrographically similar to some of the rocks of the Copper Cliff Formation, and are probably genetically related to the Copper Cliff Formation.

Phemister (1956), described the Copper Cliff Formation as an intrusive body, but work by the authors has shown that the contact between the Copper Cliff and underlying Stobie Formations is conformable and locally gradational. Pyroclastic materials, some units of which show evidence of deposition and reworking in water in the form of crossbedding and graded bedding, constitute approximately 50 percent of the Copper Cliff Formation. The rocks of the Copper Cliff Formation probably represent the felsic differentiates of a volcanic cycle which began with the extrusion of the Elsie Mountain basalts.

The stratigraphy of the Copper Cliff Formation has not been fully defined, but generally consists of interstratified felsic pyroclastic rocks and felsic flows. The major lithologies, in approximate order of abundance include: crystal tuff (quartz-feldspar porphyry), flow-banded and massive rhyolite, and fragmental units (lithic tuff, "ghost fragmental" rhyolite). These rocks mainly have the composition of rhyolite, although dacite is also present.

The crystal tuffs are generally massive and nonbedded, although crude size sorting of phenocrysts is present locally. The fragmental units consist of angular fragments of rhyolite or dacite in a rhyolitic matrix. Crude bedding in some units is revealed by variations in fragment size and packing, and in matrix composition and texture. Some units show grading in the size of fragments from bottom to top.

Layering developed in the rhyolite is caused mainly by variations in grain size. Burrows and Rickaby (1934) suggest that some of the flow-banded rhyolite may represent welded tuff. Three units of flow-banded rhyolite ranging in thickness from 60 to 200 feet (18 to 60 m) can be traced over a strike length of about 5 miles (8.0 km). A fine-grained pink, massive rhyolite unit which occurs near the top of the Copper Cliff Formation in Waters and McKim Townships has a maximum thickness of approximately 100 feet (30 m) and is exposed over a strike length of 6 miles (9.6 km).

A sulphide-bearing crystal tuff unit up to 50 feet (15 m) thick occurs near the base of the Copper Cliff Formation in Waters and McKim Townships. Sulphide minerals, mainly pyrite and pyrrhotite, are present in amounts of about 5 percent by volume.

Table 4 | CHEMICAL AND MODAL ANALYSES OF ROCKS OF THE COPPER CLIFF FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

Chemical Analyses, Major Components in Weight Percent

	1	2	3
SiO_2	71.10	83.50	78.30
Al_2O_3	12.10	8.61	12.42
Fe_2O_3	1.30	...	...
FeO	0.31	0.55	4.59
MgO	0.22	0.07	0.36
CaO	2.71	0.14	0.46
Na_2O	1.39	3.06	4.05
K_2O	6.57	2.96	1.63
H_2O^+	1.76	0.07	...
H_2O^-	0.24	0.02	...
CO_2	...	0.05	...
TiO_2	0.28	0.05	0.04
P_2O_5	...	0.01	0.01
MnO	0.10	0.01	...
FeS_2	0.02	0.01	...
Total	98.10	99.11	101.86
S.G.	2.69	2.62	n.d.

Trace Elements in PPM

Ba	...	150	...
Cr	...	...	...
Co	...	7	...
Cu	...	6	...
Ga	...	15	...
Ni	...	10	...
Pb	...	15	...
Sc	...	...	...
Sr	...	50	...
V	...	150	...
Y	...	15	...
Zr	...	100	...
Zn	...	10	...

Notes
1. Dacite, Waters Township.
2. Rhyolite (Fragmental?), Waters Township.
3. Felsic intrusion, Graham Township.

Abbreviations
... – Not detected
n.d. – Not determined
S.G. – Specific Gravity

Modal Analyses in Volume Percent

	1	2
Plagioclase	8	10
Potassium Feldspar	15	18
Quartz	70	70
Chlorite	1	x
Biotite	1	x
Muscovite	2	2
Epidote	1	...
Carbonate	2	x
Apatite	...	...
Iron Oxides	x	x
Sulphides	x	x
Sphene	x	...
Plagioclase Composition		

Notes
2. Dacite, Waters Township.
1. Rhyolite, Waters Township.

Abbreviations
x – Trace amounts detected
... – Not detected

Petrography and Chemistry

The felsic metavolcanics of the Copper Cliff Formation are composed of a fine-grained intergrowth of microperthite, orthoclase, plagioclase, and quartz with minor sericite, biotite, chlorite, epidote, carbonate, garnet, iron oxides, and sulphides (Table 4). Phenocrysts of quartz, plagioclase, and microperthite (up to 1 cm in diameter) of the crystal tuffs are commonly deformed and rotated, reflecting the well-developed tectonic foliation.

Complete chemical analyses of rocks of the Copper Cliff Formation are given in Table 4, the rocks are classified according to their normative compositions in Figure 4, and variations in their petrographic indices and composition with stratigraphic height are portrayed in Figures 5, 6, and 7.

SALMAY LAKE FORMATION

Distribution and Lithology

Mafic metavolcanics, representing the eastward extension of the Salmay Lake Formation (Robertson 1970), intercalated with conglomerate, sandstone, and pelite of the Matinenda and McKim Formations, form the basal part of the Huronian sequence in Hyman, Baldwin, and Shakespeare Townships. This volcanic accumulation, which may attain a thickness of up to 5,000 feet (1 500 m), can probably be correlated with the Elsie Mountain and Stobie Formations of the Sudbury area.

In Shakespeare Township the sequence consists of fine- to medium-grained mafic igneous rocks that probably represent flows and intrusions; intercalations of pelitic rocks, probably tuffaceous in part, and Matinenda-type quartz-feldspar sandstone and quartz-pebble conglomerate occur in the sequence. Amygdules are common in the metavolcanics. Several units of agglomeratic rocks that consist of mafic metavolcanic fragments in a basaltic matrix are present. In Baldwin Township well-bedded mafic tuff, pelite, polymictic conglomerate, and quartz-feldspar sandstone are intercalated with fine- to medium-grained massive and amygdaloidal flows.

Petrography and Chemistry

The Salmay Lake metavolcanics and metasediments are petrographically and chemically similar to their counterparts in the Elsie Mountain and Stobie Formations (Table 5). The metavolcanics consist of variable amounts of saussuritized plagioclase and amphiboles, with lesser amounts of quartz, biotite, chlorite, carbonate, garnet, sphene, iron oxides, and sulphides. The amygdules consist of quartz, plagioclase, chlorite, and amphiboles and some display concentric mineral zoning.

The conglomeratic rocks intercalated with the metavolcanics typically consist of abundant (50 percent to 70 percent) pebbles and cobbles, mainly of mafic metavolcanics, but also include granite, quartz, and quartzite megaclasts, in a matrix rich in biotite, chlorite, and garnet of metamorphic origin.

Table 5 MODAL AND CHEMICAL ANALYSES OF ROCKS OF THE SALMAY LAKE FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

Modal Analyses Major Components in Volume Percent	1	2	3
Plagioclase	42.6	28	16.5
Amphibole	44.9	62	65.4
Biotite	4.3		
Chlorite			...
Epidote	2.7	2	...
Quartz		5	8.6
Carbonate			
Sphene			
Iron-titanium Oxides	5.5	3	9.5
Sulphides		x	
Accessories	x	x	...
Plagioclase Composition	Saussuritized	Saussuritized	$An_{30\pm5}$

Chemical Analyses Major Components in Weight Percent	1	2
SiO_2	48.60	53.90
Al_2O_3	14.70	13.40
Fe_2O_3	3.22	2.55
FeO	10.40	10.20
MgO	4.67	4.31
CaO	10.10	8.55
Na_2O	2.22	2.91
K_2O	0.92	1.49
H_2O^+	1.54	1.45
H_2O^-	0.09	0.08
CO_2	0.35	0.33
TiO_2	1.60	1.03
MnO	0.23	0.29
P_2O_5	0.07	0.05
S	0.01	0.01
Total	98.72	100.55
S.G.	3.06	2.93
Trace Elements in PPM		
Ba	200	500
Co	40	50
Cr	80	20
Cu	50	90
Ga	20	20
Ni	100	100
Pb	40	10
Sc	25	30
Sr	200	200
V	250	150
Y	30	50
Zn	120	120
Zr	150	150

1. Porphyroblastic metabasalt, Shakespeare Township.
2. Amygdaloidal meta-andesite, Shakespeare Township.
3. Diabasic, Shakespeare Township.

Abbreviations
S.G. – Specific Gravity
x – Trace amounts detected
... – Not detected

MATINENDA FORMATION

Lithology and Lithological Variations

Rocks of the Matinenda Formation include sandstone, pelite, and conglomerate; in that order of abundance. The contacts of the Matinenda Formation with the Salmay Lake and Stobie Formations are conformable. There is extensive interstratification of Matinenda-type sandstone with mafic flows, tuffs, and pelitic metasediments. In the Agnew Lake Mine area in Hyman Township where the Matinenda Formation is approximately 700 feet (200 m) thick, sandstone composes approximately 60 percent of the formation. Oligomictic quartz-pebble conglomerate lenses range in thickness from a few inches (10 cm) to about 15 feet (4.6 m) and occur at several stratigraphic levels. The main conglomeratic zones are about 130 feet (40 m) thick, and are located near the base and top of the Matinenda Formation. Individual conglomerate lenses can commonly be traced along strike for only a few hundred feet (120 m). In Baldwin Township, the lower conglomeratic part of the Matinenda Formation exhibits several upward-coarsening cycles (see Section 17, Chart C, back pocket). Each cycle consists of a lower pyritic sandstone grading upward into a medium- to coarse-grained, commonly pebbly protoquartzite unit that in turn grades into oligomictic quartz-pebble conglomerate. In several cycles, the lower silty unit is absent, and pebbly sandstone of the succeeding unit lies on a scoured surface developed on the conglomerate of the preceding cycle.

As the Matinenda Formation is traced eastward, a progressive increase in the amount of pelitic and volcanic rocks occurs at the expense of sandstone and oligomictic quartz-pebble conglomerate. For example, a few miles (8 km) east of the Agnew Lake Mine in Drury Township, sandstone constitutes less than one-half of the lower part of the Huronian sequence; only a few, thin quartz-pebble conglomerate lenses are present. As well as these facies changes, the sandstones exhibit a general decrease in average grain size and an increase in the amount of argillaceous matrix eastward.

In southern Hyman Township, and in adjacent Baldwin and Porter Townships, the Matinenda Formation is approximately 600 to 1,000 feet (180 to 300 m) thick, is dominantly (80 percent) sandstone and thin (1 inch to 7 feet; 2.5 cm to 2.1 m) oligomictic quartz conglomerate lenses are confined mainly to a zone about 100 feet (30 m) thick near the base. The average grain size of the conglomerate matrix decreases southward from about 1.5 mm in northern Hyman Township to about 1.0 mm in southern Hyman Township and adjacent areas. Similarly, the average feldspar content decreases from about 10 percent to 5 percent as do the amounts and average grain size of detrital minerals such as monazite (Young, D. 1962).

Variations are also discernible from the base to the top of the Matinenda Formation at any one locality. Coarse arkose and oligomictic quartz-pebble conglomerate lenses tend to be concentrated in the basal part of the formation. A general upward decrease occurs in the average grain size of the sandstones from about 1 mm to 0.5 mm or less. The amount of pelitic material as members, interbeds, silty partings, and sandstone matrix increases upward. The average thickness of quartz pebble conglomerate lenses decreases upward from about 1 to 3 feet

(0.3 to 0.9 m) to 6 inches (15.0 cm) to 1 foot (0.3 m). Pebble size decreases from an average of about 1 inch (2.5 cm) and a maximum of about 12 inches (30.0 cm) to an average of about ½ inch (1.3 cm) and a maximum of about 2 inches (5 cm).

Petrography

Sandstones of the Matinenda Formation typically are medium to coarse grained, greenish or pinkish, and are rich in feldspars and micas. Most are feldspathic protoquartzites but lesser amounts of greywacke, subgreywacke, arkose, and orthoquartzite are also present (Figure 9). The sandstones consist of subangular to subrounded grains of quartz (range from 25 percent to 98 percent; average 75 percent) and feldspars (range from 1 percent to 60 percent; average 5 percent to 10 percent) in a matrix of phyllosilicates, and silt-size quartz and feldspars (range from 1 percent to 40 percent; average 10 percent to 15 percent). Rock fragments, mainly granitoid varieties, are commonly present in minor amounts (less than 5 percent). The sand-size grains are poorly to moderately sorted, and were probably originally subangular to subrounded. Average grain size is in the range 0.5 to 1 mm but finer grained (0.05 to 0.5 m) argillaceous sandstone, coarse-grained (1 to 3 m) arkose, and very coarse arkosic grit or pebbly arkose with quartz granules and pebbles 3 to 20 mm in diameter are present.

Quartz is probably derived mainly from vein, pegmatitic or plutonic sources. Potassic feldspar and plagioclase are present; the ratio of potassic feldspar to plagioclase ranges from about 1:1 to 10:1 and averages 3:1. Feldspars are extensively replaced by sericitic mica. Sericite, a muscovite of metamorphic origin, is the chief phyllosilicate, but minor amounts of reddish biotite and pale green chlorite are commonly also present. Accessory minerals, which are present in amounts of 0.5 percent to 1 percent include zircon, pyrite, pyrrhotite, monazite, apatite, sphene, ilmenite, and magnetite.

Oligomictic quartz-pebble conglomerate of the Matinenda Formation consists of well-rounded, now mainly tectonically flattened, quartz pebbles in a generally poorly sorted, medium- to coarse-grained micaceous feldspathic sandstone matrix. The pebbles, which constitute approximately 20 percent to 80 percent, and average 50 percent of the rock, are mainly grey, black, white or reddish quartz of vein, pegmatitic, and plutonic derivation. Chert, quartzite, and granitic pebbles are rarely present. The pebbles range in maximum dimension from less than ¼ inch (0.6 cm) to about 12 inches (30 cm), but most are ½ to 1 inch (1.3 to 2.5 cm) in diameter.

The matrix of most quartz-pebble conglomerate lenses consists of medium- to coarse-grained (range in grain size 0.5 to 10 mm; average 1 to 2 mm) subangular to subrounded quartz, feldspars, and rock fragments in a matrix of phyllosilicates, quartz, and feldspars. Compositionally, the conglomerate matrix is practically identical to the enclosing feldspathic sandstones (see Figure 9). However accessory minerals are generally more abundant in the conglomerate and constitute 0.5 percent to 9 percent and average about 2 percent of the rock. Accessory minerals include pyrite, pyrrhotite, ilmenite, zircon, monazite, apatite, garnet, tourmaline, sphene, uranothorite, 'brannerite', uraninite, thorianite, chalcopyrite, and galena (Card 1959; Young, D. 1962).

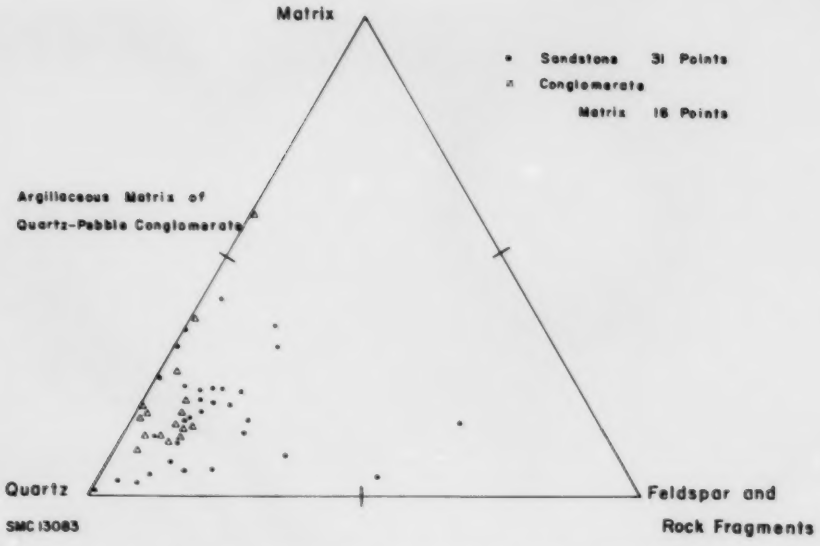

Figure 9–Mineralogical composition of rocks of the Matinenda Formation.

A second type of quartz-pebble conglomerate is locally present. This rock consists of quartz pebbles in a silty or argillaceous matrix. A few granitic and greenstone fragments are commonly also present. The pebbles generally constitute less than 30 percent of the rock and average 3 to 6 inches (7.6 to 15.2 cm) in diameter.

Polymictic conglomerate lenses of two types are present. Polymictic paraconglomerate similar to the Ramsay Lake conglomerate occurs at several stratigraphic positions; especially near the base of the formation where the basement rocks are of granitic composition. This rock consists of 15 percent to 30 percent granitic, quartz, and mafic igneous pebbles averaging 1 inch to 3 inches (2.5 to 7.6 cm) in diameter in feldspathic sandstone (protoquartzite, subgreywacke) matrix.

The other type, polymictic orthoconglomerate, typically occurs in association with mafic volcanic rocks, and consists of up to 70 percent pebbles and boulders of mafic volcanic, granitic, and metasedimentary derivation. The pebbles and boulders are in a pelite or greywacke matrix.

Two main types of pelitic rocks are present, delicately laminated argillite, and siltstone or silty sandstone. Laminated argillite commonly occurs as distinct units a few feet to about 100 feet (30 m) thick. Laminated argillite is a fine-grained (probably clay- to fine-silt size originally) rock rich in phyllosilicates.

Siltstone occurs as units up to several hundred feet (120 m) thick with interbedded sandstones and as bedding-plane partings in the dominantly sandstone sequences. Siltstone is rich in phyllosilicates, quartz, and feldspars; its original grain-size was probably in the silt- to fine-sand range.

McKIM FORMATION

Lithology and Lithological Variations

The McKim Formation conformably overlies the Matinenda, Stobie, Salmay Lake, and Copper Cliff Formations. There is extensive interstratification of McKim-type sedimentary rocks with Matinenda-type sandstones and metavolcanics of the Salmay Lake, Stobie and Copper Cliff Formations.

Three lithological facies are distinguished in the McKim Formation and are named in this report the greywacke facies, the laminated argillite facies, and a quartz sandstone facies.

The greywacke facies consists of interbedded greywacke and siltstone with minor laminated argillite and siltstone. Ripple marks, ripple-drift cross-lamination, parallel lamination, graded beds, and Bouma cycles are present. The greywackes are fine- to coarse-grained, and commonly have graded bedding. The greywacke facies is dominant in the eastern part of the report-area. For example, in Waters and Graham Townships, the greywacke facies constitutes approximately 50 percent of the McKim Formation which is here some 5,000 to 6,000 feet (1 500 to 1 800 m) thick. Westward, the greywacke component decreases in amount, and in Denison Township constitutes only about 35 percent of the McKim Formation; the remainder of the formation is laminated argillite (50 percent) and quartz sandstone (20 percent).

In the east part of the report-area, bedding in this facies ranges from a few inches to about 10 feet (3 m) and averages 2 feet (0.6 m). Sequences showing relatively complete Bouma cycles (see Figure 2) are common. Divisions such as "A" (graded greywacke), "B" (parallel laminated), "C" (ripple cross-laminated), and "D" (parallel laminated) or "E" (pelitic) are shown. In the western part of the report-area the bedding is thinner (2 to 4 inches; 5.0 to 10.0 cm), and commonly only Bouma cycles "B" and "E" or "C" and "E" are present.

The laminated argillite facies consists of laminated argillite, siltstone, and subordinate amounts of fine- to medium-grained greywacke. Bedding thickness rarely exceeds 6 inches (15 cm) and is commonly less than 1 inch (2.5 cm). Although graded beds, ripple marks, and cross-lamination are present, the characteristic feature of the facies is delicate, varve-like parallel-lamination. Rhythmic alternations of light-coloured siltstone, fine sandstone laminae, and dark coloured pelitic (clay-silt) laminae are approximately 1 to 50 mm thick. Individual laminae maintain constant thickness over distances of at least 100 feet (30 m). The laminated argillite facies is dominant in the west, for example in Hyman Township where it comprises approximately 80 percent of the McKim Formation.

The quartz sandstone facies consists of fine- to medium-grained argillaceous sandstone (protoquartzite, subgreywacke) rich in quartz and feldspar. Interbeds and units of these rocks occur throughout the McKim Formation. In addition, sequences of medium- to coarse-grained feldspathic sandstone and very coarse grained quartz-feldspar grit or fine conglomerate are near the base of the McKim Formation in the east part of the report-area. These rocks represent the eastward extension of feldspathic sandstones and conglomerates that in the west are of sufficient thickness and continuity to distinguish as a separate formation, the

Matinenda Formation. The sandstone facies constitutes approximately 10 percent of the McKim Formation, except in the east where it amounts to 20 percent to 30 percent of the McKim Formation.

Petrography and Chemistry

Greywacke of the McKim Formation is composed of fine- to coarse-grained (0.1 to 2 mm), poorly sorted sand in an abundant finer grained (silt to fine sand) matrix. The proportion of sand to silt is highly variable, and every gradation from greywacke through silty greywacke and sandy siltstone to siltstone is present. Most greywackes are quartz-rich, although lithic and feldspathic varieties are present, especially in the east. In the rocks studied (Figure 10), quartz ranges from 25 percent to 50 percent and averages about 35 percent; feldspars and rock fragments constitute up to about 10 percent and average 5 percent; and matrix materials range from 45 percent to 70 percent and average 60 percent.

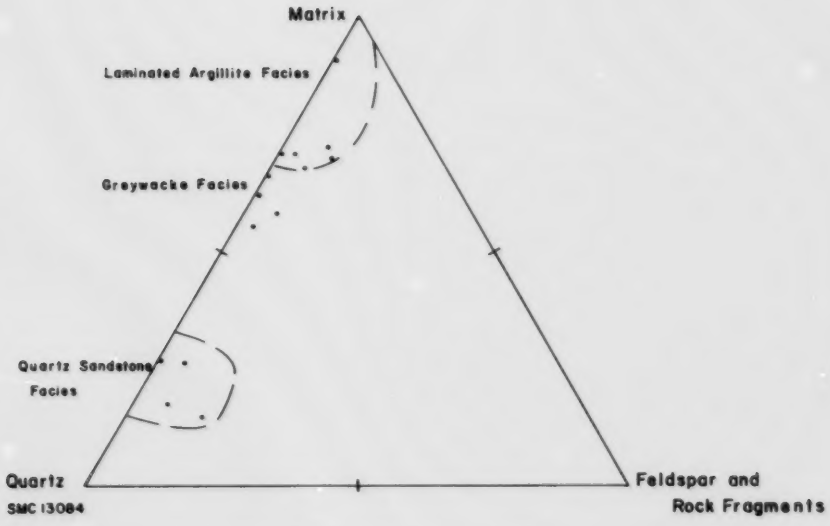

Figure 10–Mineralogical composition of rocks of the McKim Formation.

Plagioclase (albite to andesine) and potassic feldspar are present; generally plagioclase is the most abundant. Rock fragments, which are abundant only in the relatively thick-bedded, coarse-grained greywacke of the eastern part of the area, include mafic igneous (metavolcanic?), granitic, and metasedimentary varieties. The greywacke matrix is composed mainly of micaceous minerals (muscovite, chlorite, and biotite) of metamorphic origin. Accessory minerals include sphene, ilmenite, magnetite, pyrite, pyrrhotite, epidote, and zircon. Large staurolite, biotite, and garnet porphyroblasts are conspicuous in some areas.

Siltstone and sandy siltstone, present in both the greywacke and laminated argillite facies, are fine-grained, poorly to moderately sorted, grey to black rocks. They consist of silt- to fine-sand size (approximately 0.01 to 0.05 mm) angular grains of quartz and feldspars with abundant interstitial micas and chlorite. These rocks are mineralogically and chemically similar to greywacke, except that micaceous minerals are more abundant.

The laminated argillite is a dark grey, fine-grained rock. Recrystallization has made it impossible to estimate original grain size in most samples studied; the original rock probably consisted of variable proportions of clay-size and silt-size material. The present texture is one of silt-size (generally 0.02 mm or less) grains of quartz and feldspars in an abundant micaceous matrix. The major minerals, which are primarily of metamorphic or recrystallized sedimentary origin include quartz (approximately 20 percent), plagioclase (albite to andesine) (approximately 10 percent), micas (approximately 50 percent), and chlorite (approximately 10 percent). Muscovite is abundant generally, and variable amounts of biotite, chlorite (ripidolite-type), almandine, chloritoid and staurolite are present. Accessory minerals include sphene, ilmenite, pyrite, pyrrhotite, and zircon. In comparison with the "average shale" (Pettijohn 1957), laminated argillite is relatively rich in alumina (18 percent to 25 percent), total iron ($FeO + Fe_2O_3$—5 percent to 10 percent), and titania (0.7 percent to 1.0 percent), and poor in CaO (0.5 percent to 2 percent) (Table 6). The Al_2O_3/Na_2O ratio averages about 17, the CaO/Na_2O ratio about 0.8, and the K_2O/Na_2O ratio about 2 for the rocks analyzed. Laminated argillite is enriched in FeO relative to Fe_2O_3, and the ratio of the two oxides ranges from 1 to 4 and averages about 2.5.

The grey to pinkish, fine- to medium-grained argillaceous sandstone interbeds and units which occur throughout the McKim Formation are mainly of protoquartzite and subgreywacke composition. These rocks are poorly to moderately sorted, and consist of fine- to medium-sand size fragments of quartz (60 percent to 80 percent), feldspars (up to 15 percent) and rarely, rock fragments, in a finer grained (silty) matrix (10 percent to 30 percent) of muscovite, biotite, chlorite, quartz, and feldspars. Both plagioclase and potassic feldspar are present, generally in about equal proportions. The chief mica is muscovite, and minor amounts of sphene, iron-titanium oxide minerals, sulphide minerals, and carbonate also occur.

The medium- to coarse-grained feldspathic sandstone and very coarse arkosic grit or fine conglomerate in the lower part of the McKim Formation in the east part of the report-area, are petrographically similar to their counterparts in the Matinenda Formation in the western part of the report-area.

Table 6 | CHEMICAL ANALYSES OF ROCKS OF THE McKIM FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

Major Components in Weight Percent

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	CO_2	TiO_2	MnO	P_2O_5	S	Total	S.G.
(1)	55.07	21.50	2.72	6.04	3.00	0.98	1.43	3.01	3.53	0.02	0.12	0.98	0.05	0.11	...	98.56	2.80
(2)	60.73	21.18	3.23	4.16	2.75	0.79	0.90	2.30	2.61	...	0.20	0.74	0.04	0.09	...	99.72	2.82
(3)	57.14	25.61	2.33	4.17	2.39	1.01	1.01	2.66	2.02	...	0.12	0.71	0.05	0.09	...	99.31	2.89
(4)	57.75	19.19	2.98	7.86	2.44	2.27	2.34	0.98	2.48	0.02	0.02	0.82	0.07	0.11	...	99.33	2.75
(5)	62.00	18.90	1.24	4.24	3.30	1.64	2.17	1.88	3.56	0.05	...	0.64	0.05	0.11	...	99.78	n.d.
(6)	54.60	23.90	1.32	5.20	3.60	0.82	0.90	4.12	3.78	0.04	...	0.96	0.04	0.18	...	99.46	n.d.
(7)	55.55	22.80	1.40	5.28	3.20	0.56	0.72	4.65	4.81	0.07	...	0.84	0.09	0.15	...	100.12	n.d.
(8)	60.40	22.40	4.11	3.97	2.77	0.01	0.86	2.54	2.81	0.12	0.18	0.98	0.06	0.08	<0.01	101.30	2.96
(9)	65.60	16.30	0.74	5.45	2.67	0.89	1.41	...	2.42	0.26	0.04	0.79	0.07	0.12	...	96.73	2.76

Trace Elements in PPM

	Ba	Co	Cr	Cu	Ga	Ni	Pb	Sc	Sr	V	Y	Zn	Zr	Be
(8)	500	10	200	15	20	80	15	20	100	200	30	15	150	3

Notes

(1) Metapelite (laminated siltstone-argillite), lower greenschist facies metamorphism, Drury Township.
(2) Metapelite (laminated siltstone-argillite), lower almandine-amphibolite facies metamorphism, Hyman Township.
(3) Metapelite (laminated siltstone-argillite), lower almandine-amphibolite facies metamorphism, Hyman Township.
(4) Fine-grained silty sandstone, upper greenschist facies metamorphism, Hyman Township.
(5) Metapelite (laminated siltstone-argillite), upper greenschist facies, Merritt Township.
(6) Metapelite (laminated siltstone-argillite), upper greenschist facies, Merritt Township.
(7) Metapelite (laminated siltstone-argillite), upper greenschist facies, Merritt Township.
(8) Metapelite (laminated siltstone-argillite), lower almandine-amphibolite facies, Shakespeare Township.
(9) Greywacke, greenschist facies, Graham Township.

Abbreviations

S.G. – Specific Gravity
n.d. – Not determined
... – Not detected
< – Less than

Hough Lake Group

RAMSAY LAKE FORMATION

Lithology and Lithological Variations

The Ramsay Lake Formation consists mainly of a polymictic paraconglomerate and pebbly sandstone, and ranges in thickness from 200 to 600 feet (60 to 180 m). The basal two-thirds of the Ramsay Lake Formation consists of polymictic paraconglomerate and pebbly sandstone with a few interbeds of sandstone, siltstone, and greywacke. The upper one-third of the formation consists of sandstone with pebbly sandstone and polymictic paraconglomerate lenses. The contact between the Ramsay Lake Formation and the underlying McKim Formation is generally abrupt but conformable. Locally, there is evidence for erosion at the base of the Ramsay Lake Formation. Conversely, in other localities, for example in southern Graham Township, greywacke and conglomerate are interstratified in a transitional contact zone some 30 feet (9 m) thick (see Section 13, Chart A, back pocket).

In the lower part of the Ramsay Lake Formation, a rapid increase in pebble size occurs from an average of less than 1 inch (2.5 cm) to about 3 inches (7.5 cm), and pebble content (from less than 10 to 15 to 30 percent). These increases are followed by a general decrease in average pebble size and content. Also a general upward increase occurs in the amount of sandstone. Only a few thin sandstone interbeds, which are commonly disrupted, are present in the lower two-thirds of the Ramsay Lake Formation, whereas the upper one-third is dominantly sandstone. Within the conglomeratic rocks an upward increase in the degree of sorting is shown by the appearance of stratification. Thick, 5 to 30 feet (1.5 to 9 m) stratification units in the conglomerate are defined by sandstone interbeds and by variations in the conglomerate matrix, pebble size, and pebble content.

The Ramsay Lake Formation varies in thickness from about 200 to 300 feet (60 to 90 m) in the north to about 500 to 600 feet (150 to 180 m) in the central parts of the report-area. There are corresponding lithological changes. In the thicker sections, polymictic paraconglomerate constitutes approximately 90 percent of the formation, but in the thinner sections, sandstone, sparsely pebbled sandstone, and siltstone are dominant (50 percent to 60 percent). These facies variations may be attributable to increased reworking in the depositional environment because the relatively non-conglomeratic parts of the Ramsay Lake Formation show features such as bedding, crossbedding, and ripples that are absent in the massive or poorly stratified conglomeratic portions.

Petrography and Chemistry

The polymictic paraconglomerate is a buff-weathering rock composed of 10 percent to 30 percent pebbles, cobbles, and boulders in a feldspathic sandstone matrix. The rock fragments range in maximum dimension from less than 1 inch (2.5 cm) to about 5 feet (1.5 m) and commonly average about 1 to 2 inches (2.5 to

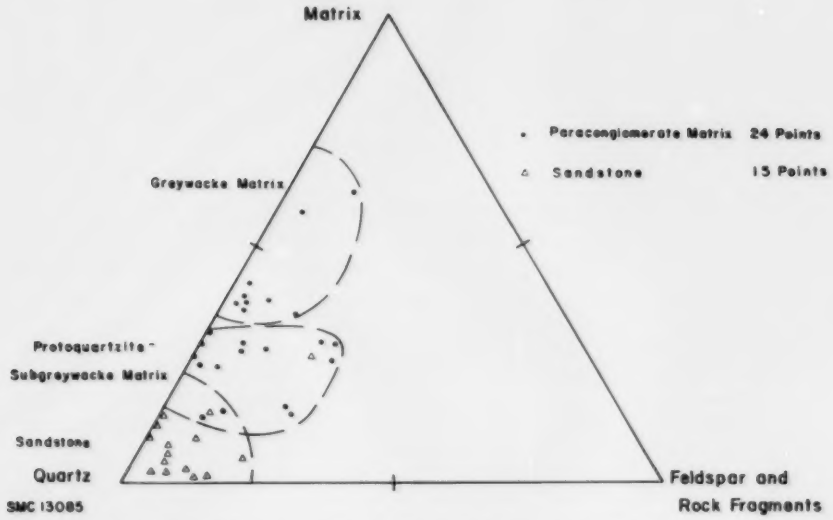

Figure 11–Mineralogical composition of rocks of the Ramsay Lake Formation.

5.0 cm). The rock fragments consist of felsic igneous (granitic and felsic volcanic fragments; 25 percent to 60 percent), mafic igneous (gabbroic and mafic volcanic fragments; 25 percent to 40 percent), and quartzose (vein quartz and quartzite fragments; 10 percent to 30 percent) types and are angular to rounded. Generally the fragments are unsorted as to size or shape. The quartzite fragments are up to 10 feet (3 m) in maximum dimension and most are contorted and have diffuse boundaries; such features show that they were derived from the disruption of pre-existing, semi-consolidated sandstone interbeds. Some of the igneous rock fragments show one or more flat surfaces indicative of faceting.

The conglomerate matrix is a fine- to coarse-grained (0.1 to 2 mm; average 0.5 mm) poorly to moderately sorted feldspathic sandstone characterized by abundant, well-rounded quartz grains and granules. The well-rounded nature of these grains contrasts strongly with the bulk of the matrix grains which are angular to sub-rounded. The quartz grains and granules probably represent material derived from pre-existing sandstone units.

The matrix varies in composition from protoquartzite to greywacke, and consists of 25 percent to 75 percent sand-size quartz, up to 25 percent feldspar and rock fragments, and 20 percent to 70 percent matrix materials (phyllosilicates plus silt size quartz and feldspar) (Figure 11). Feldspar commonly constitutes about 10 percent of the matrix and is dominantly (60 percent to 80 percent) potassic; but plagioclase is also present. Sand-size fragments are generally present in amounts of 5 percent or less, but locally constitute up to 15 percent of the rock matrix. Accessory minerals are abundant, commonly constituting 2 percent to 3 percent of the rock, and include pyrite (or pyrrhotite), iron-titanium oxides, zircon, apatite, sphene, leucoxene, and monazite.

Table 7 | CHEMICAL ANALYSES OF ROCKS OF THE RAMSAY LAKE AND BRUCE FORMATIONS; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

	Major Components in Weight Percent														
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	CO_2	TiO_2	MnO	P_2O_5	S	Total
(1)	88.90	5.44	0.26	0.92	0.32	0.19	0.60	2.11	0.81		...	0.19	0.01	0.04	...	99.79
(2)	74.25	10.39	0.26	5.32	2.12	0.51	2.15	1.28	2.26		0.27	0.49	0.05	0.15	...	99.50
(3)	83.55	8.05	1.08	0.98	0.65	0.34	1.25	2.65	1.06		0.26	0.20	0.08	0.04	...	100.19
(4)	73.50	11.92	1.39	1.88	2.18	0.20	3.50	3.12	1.48		...	0.46	...	0.11	...	99.74
(5)	70.55	12.10	0.88	3.64	2.02	1.64	2.84	2.49	2.20		0.72	0.56	...	0.14	...	99.78

(1) Paraconglomerate matrix, Ramsay Lake Formation.
(2) Paraconglomerate matrix, Ramsay Lake Formation.
(3) Paraconglomerate matrix, Ramsay Lake Formation.
(4) Paraconglomerate matrix, Bruce Formation.
(5) Paraconglomerate matrix, Bruce Formation.

Abbreviation
... – Not determined

The chemically analyzed Ramsay Lake conglomerates have an average K_2O/Na_2O ratio of 1.5, a CaO/Na_2O ratio of 0.25, and an Al_2O_3/Na_2O ratio of about 6 (Table 7).

The upper part of the Ramsay Lake Formation is mainly composed of medium- to coarse-grained feldspathic sandstone, commonly containing a few (less than 10 percent) scattered, rock fragments that average about 1 inch (2.5 cm) and range up to 6 inches (15.2 cm) in diameter. The sandstone is a moderately sorted rock similar in composition and texture to the matrix of the better sorted conglomerate. The most common sandstone is a medium-grained, feldspathic protoquartzite consisting of about 75 percent quartz, 10 percent feldspars, and 15 percent interstitial matrix.

The sandstone interbeds, lenses, and blocks that occur in the central part of the formation typically are fine-grained, white feldspathic quartzite and orthoquartzite. Most consist of about 85 percent quartz, 10 percent feldspars, and 5 percent interstitial matrix.

Siltstone and greywacke interbeds and units occur mainly in the lower part of the Ramsay Lake Formation. In the basal part of the formation, siltstone and medium- to coarse-grained greywacke, commonly containing small, less than ½ inch (1.3 cm) scattered pebbles, are interbedded with conglomeratic rocks. Lenses of coarse- to very coarse grained quartz-rich greywacke with abundant well-rounded grains and granules of quartz also occur. Further up in the Ramsay Lake Formation are interbeds and units of fine-grained greywacke and sandy siltstone lithologically similar to rocks of the overlying Pecors and underlying McKim Formations.

PECORS FORMATION

Lithology and Lithological Variations

The rocks of the Pecors Formation, siltstone, argillite, greywacke, and quartz-feldspar sandstone, are lithologically similar to those of the McKim Formation. Sedimentary structures, including graded beds, ripple marks, and cross-lamination are well developed. Sequences displaying Bouma divisions are present, some begin with the "A" (graded greywacke) division, but many begin with the "B" (parallel laminated) or "C" (cross-laminated) divisions. The contact with the underlying Ramsay Lake Formation is conformable and gradational over a stratigraphic interval that is some 20 feet (6 m) thick.

In the central part of the report-area, the Pecors Formation is approximately 1,400 to 2,000 feet (430 m to 600 m) thick and can be divided into three intergradational units. The lower unit, 700 to 900 feet (200 to 270 m) thick, consists of interbedded fine- to medium-grained greywacke, feldspathic sandstone, siltstone and argillite. The proportion of feldspathic sandstone decreases upward from approximately 70 percent at the base, to 10 to 20 percent at the top of the unit. The middle unit comprises some 400 to 500 feet (120 to 150 m) of siltstone, argillite, and fine-grained greywacke with minor (less than 10 percent) feldspathic sandstone interbeds in the lower and upper parts. The upper unit, which repre-

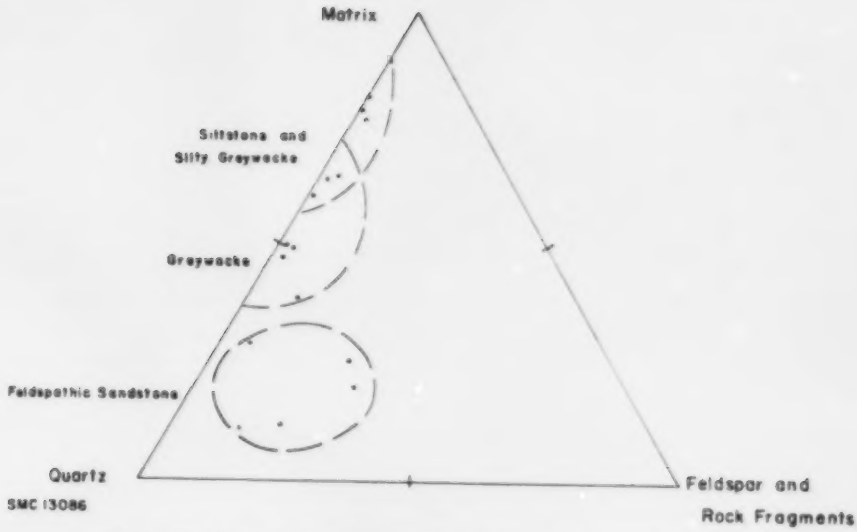

Figure 12–Mineralogical composition of rocks of the Pecors Formation.

sents the transition into feldspathic sandstone of the overlying Mississagi Formation, consists of 300 to 600 feet (90 to 180 m) of greywacke, siltstone, and feldspathic sandstone. The proportion of feldspathic sandstone and greywacke increases upward from about 10 to 70 percent.

In the northern part of the report-area, the Pecors Formation is approximately 200 to 500 feet (60 to 150 m) thick and consists of the following: a lower unit, 100 to 200 feet (30 to 60 m) of siltstone, fine-grained greywacke, and minor (10 percent) feldspathic sandstone; and an upper unit, 100 to 300 feet (30 to 90 m) of laminated siltstone, fine-grained greywacke, and feldspathic sandstone. The proportion of feldspathic sandstone increases upward in the Pecors Formation.

Petrography and Chemistry

The siltstone and argillite are fine-grained, grey to black rocks composed mainly of phyllosilicates and silt-size quartz and feldspar (Figure 12). The Pecors greywacke is a fine- to medium-grained, poorly sorted rock consisting of quartz (30 to 60 percent), feldspars and rock fragments (10 percent) in an abundant (30 to 70 percent) matrix of phyllosilicates and silt-size quartz and feldspars. Every gradation occurs from siltstone through sandy siltstone to greywacke. The feldspathic sandstone is fine- to medium-grained, poorly to moderately sorted subgreywacke and protoquartzite. Feldspathic sandstone consists of 70 to 90 percent quartz and 5 to 30 percent feldspars and rock fragments in a matrix (10 to 30 percent) of phyllosilicates, and silt-size quartz and feldspars.

Table 8 CHEMICAL ANALYSIS OF SILTSTONE OF THE PECORS FORMATION; CHEMICAL ANALYSIS BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

Major Components in Weight Percent		Trace Elements in PPM	
SiO_2	62.60	Ba	500
Al_2O_3	19.60	Co	20
Fe_2O_3	0.42	Cr	250
FeO	5.35	Cu	50
MgO	3.40	Ga	35
CaO	1.01	Ni	70
Na_2O	1.20	Pb	30
K_2O	2.17	Sc	20
H_2O^+	2.49	Sr	300
H_2O^-	0.12	V	100
CO_2	0.12	Zn	100
TiO_2	0.93	Zr	120
P_2O_5	0.08	Be	3
S	0.08		
MnO	0.07		
Total	99.64		
S.G.	2.79		

Abbreviation
S.G. – Specific Gravity

Recognizable rock fragments are not abundant, constitute less than 5 percent, and are commonly absent. The fragments are mainly of granitoid composition. Potassic feldspar and plagioclase are present; plagioclase is the main feldspar in the greywacke, whereas potassic feldspar is dominant in the feldspathic sandstone. Accessory minerals, including pyrrhotite, pyrite, iron-titanium oxides, carbonate, zircon, apatite, sphene, and leucoxene, are generally present in amounts of about 1 percent.

A chemical analysis of a laminated siltstone of the Pecors Formation (Table 8) shows that it is chemically similar to argillaceous rocks of the McKim Formation. The Al_2O_3/Na_2O, CaO/Na_2O, and K_2O/Na_2O ratios of the analyzed specimen are approximately 16, 1, and 2 respectively. The sample is rich in ferrous iron relative to ferric iron, and has an FeO/Fe_2O_3 ratio of about 12.

MISSISSAGI FORMATION

Lithology and Lithological Variations

The contact between the Mississagi and Pecors Formations is conformable and gradational over a stratigraphic interval which ranges from 100 feet to 200 feet (30 m to 60 m) in thickness.

The Mississagi Formation in the Sudbury-Espanola area is best described as a sequence of coarsening-upward sedimentary cycles consisting mainly of sandstone

with subordinate siltstone. Individual cycles are lensoid, vary in thickness from 10 feet to 250 feet (3 m to 76 m), and have sharp, but apparently non-erosional basal contacts. A typical Mississagi cycle, as described by Palonen (1971), is shown diagrammatically in Figure 13. A complete cycle, in ascending order, consists of the following units:

Unit A Fine- to medium-grained feldspathic greywacke and subgreywacke with interbedded siltstone and sandy siltstone. The beds are generally less than 6 inches (15 cm) thick, are commonly graded or laminated, and crossbedding, where present, is of the planar type.

Unit B Medium-grained quartz greywacke, subgreywacke, and feldspathic protoquartzite with minor siltstone. Beds are up to 1½ feet (0.45 m) thick. Graded beds and planar crossbeds are present.

Unit C Medium- to coarse-grained feldspathic quartzite and arkose with minor pebbly mudstone partings. Beds average 2 to 3 feet (0.6 to 0.9 m) in thickness, are lenticular, and planar. Trough crossbeds are present. Single beds generally show a distinctive crossbed pattern consisting of a lower single set of planar crossbeds up to 1 foot (0.3 m) thick which is truncated by a trough crossbedded coset up to 2 feet (0.6 m) thick. The sandstone beds are commonly overlain by sandy or pebbly mudstone with current ripples.

Unit D Medium- to coarse-grained, thick-bedded 5 to 20 feet (1.5 to 6 m) white feldspathic quartzite and arkose. Trough crossbedding is present throughout, and some beds up to 6 feet (1.8 m) thick represent individual sets of planar crossbeds.

Unit E Feldspathic quartzite with intercalated mudstone beds. Bedding in the sandstone is 2 to 3 feet (0.6 to 0.9 m) thick. Planar and festoon crossbeds are present. The mudstone is massive and commonly contains quartz and granite pebbles up to about 1 inch (2.5 cm) in diameter.

Throughout much of the report-area, the upper part of the Mississagi Formation consists of medium- to coarse-grained, thick-bedded arkose. Planar and festoon-crossbeds, graded crossbeds, and coarse laminations are typical of this unit.

Within the Mississagi Formation as a whole a general upward increase takes place in average grain size, and in degree of sorting in the sandstone; a corresponding decrease takes place in the amount of silty material in the form of sandstone matrix and intercalations. The average grain size of the Mississagi sandstone increases upward from about 0.2 mm in the lower part, to 0.3 mm in the middle part, and 0.5 mm or more in the upper part of the formation. The matrix content of the sandstone in the lower part of the formation is generally greater than 15 percent, whereas the middle and upper sandstone generally contain less than 15 percent matrix.

The thickness of individual sedimentary cycles increases upward in the Mississagi Formation. Units A and B are dominant in the lower cycles, but units C and D are dominant in the cycles of the middle and upper parts of the formation. Unit E is developed only in the upper cycles. The foregoing features indicate deposition occurred in an environment of increasing energy and winnowing activity.

The Mississagi Formation shows lateral as well as vertical lithological variations. In the northern part of the report-area, the Mississagi Formation is approximately 2,500 (760 m) to 3,000 feet (900 m) thick, and consists mainly of

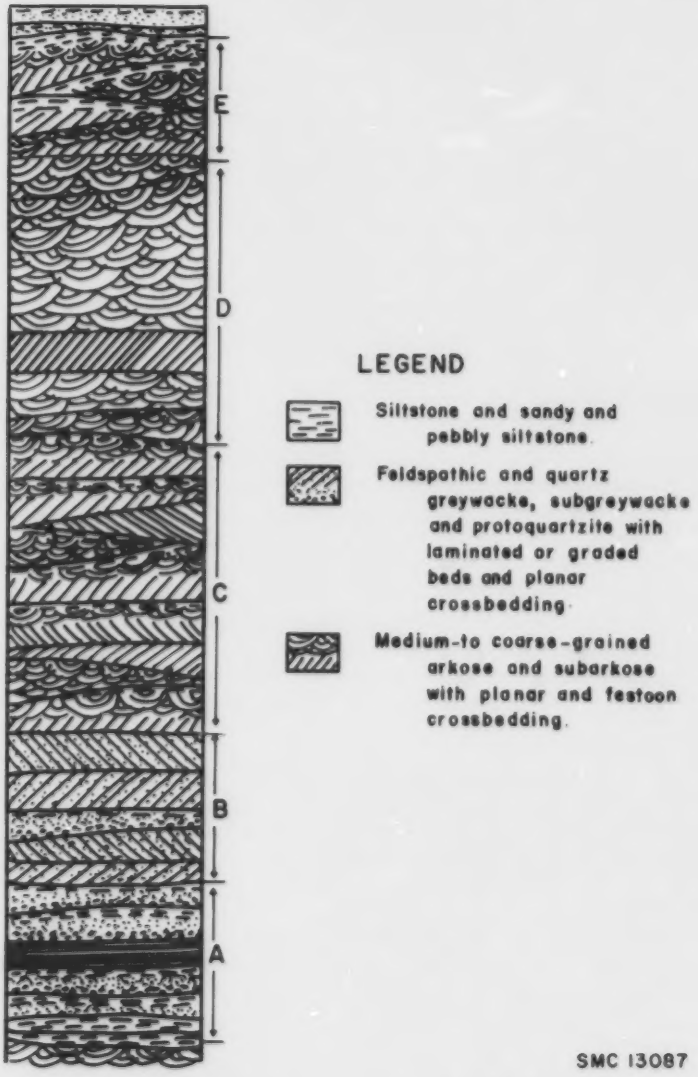

Figure 13–Typical sedimentary cycle in the Mississagi Formation, (after Palonen 1971).

medium- to coarse-grained feldspathic sandstone. Sedimentary cycles though present are not well developed, and are generally less than 100 feet (30 m) thick. Silty material occurs mainly as sandstone matrix, partings, and interbeds. In contrast, the Mississagi Formation in the southwestern and central parts of the report-area is about 5,000 feet (1 500 m) thick; sedimentary cycles are well developed and are generally in excess of 100 feet (30 m) in thickness. In the southeast, the Mississagi Formation is approximately 10,000 feet (3 000 m) thick and contains an appreciable amount of silty material in the form of sandstone matrix, interbeds, and units up to 200 feet (60 m) in thickness. Also, the upper coarse-grained arkose gives way to medium-grained feldspathic protoquartzite and subgreywacke as the formation is traced eastward toward the Grenville Front Zone.

Petrography

Sandstones of the Mississagi Formation range in composition from orthoquartzite to arkose to greywacke. Modal analyses show that the rocks contain approximately 40 to 90 percent quartz, 5 to 35 percent feldspars and rock fragments, and 5 to 30 percent interstitial matrix (phyllosilicates, silt-size quartz and feldspars), (Figure 14a).

Sandstones in the lower part of the formation and of lower parts of sedimentary cycles throughout the formation are typically fine- to medium-grained, poorly sorted greywacke, subgreywacke, and protoquartzite containing 40 to 85 percent (average 65 percent) quartz, 5 to 35 percent (average 10 percent) feldspar and rock fragments, and 10 to 35 percent (average 15 percent) matrix. Sandstones typical of the middle parts of sedimentary cycles, and generally of the middle portions of the formation, are poorly to moderately sorted, medium-grained feldspathic protoquartzite and subgreywacke, containing 60 to 75 percent (average 70 percent) quartz, 5 to 30 percent (average 10 percent) feldspars and rock fragments, and 5 to 20 percent (average 12 percent) matrix. The medium- to coarse-grained feldspathic quartzite and arkose typical of the upper parts of individual sedimentary cycles, and of the upper part of the formation as a whole, consist of approximately 5 percent to 10 percent matrix, 70 percent quartz, and 15 percent feldspars and rock fragments (Figure 14b).

The feldspars present include potassic feldspar (commonly perthitic varieties), and plagioclase (albite, oligoclase). The ratio of potassic feldspar to plagioclase ranges from about 1:1 to 2:1, and the ratio of quartz to feldspars is generally high (approximately 7).

Rock fragments are not abundant, generally constituting less than 5 percent by volume of the rock, and are commonly absent entirely (Figure 14c). The rock fragments noted include in order of abundance, granitic, felsic volcanic, and metasedimentary varieties. Locally, siltstone or argillaceous chips are relatively abundant, and range in size from microscopic dimensions to slabs a foot (0.3 m) or more in length. It is probable that such fragments were derived by the break-up of silty interbeds within the sequence, and, as such are not indicators of a metasedimentary provenance. This is in contrast to the predominantly felsic plutonic (quartz monzonite, granodiorite) provenance indicated by the other compositional criteria.

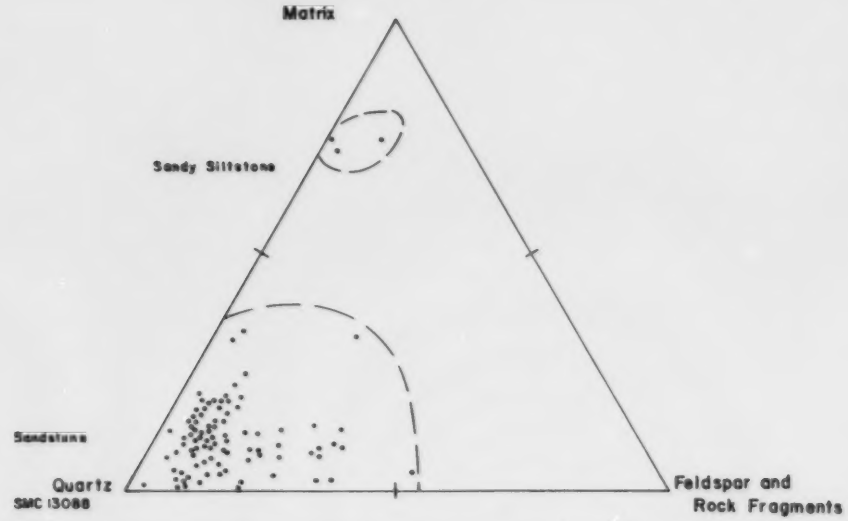

Figure 14a–Triangular diagram to show range in mineralogical composition of sandstones and siltstones in Mississagi Formation. All positions, 94 points.

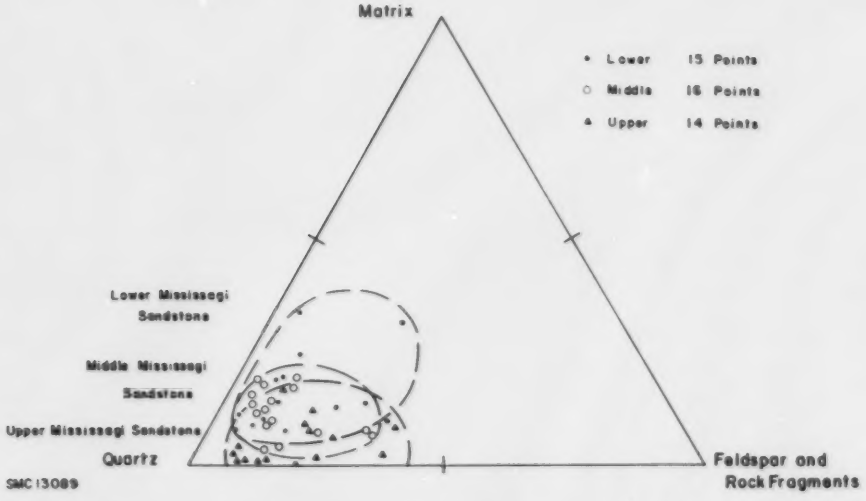

Figure 14b–Triangular diagram to show stratigraphic variation in mineralogical composition of sandstones in Mississagi Formation. Lower Mississagi Formation, 15 points; Middle Mississagi Formation, 16 points; Upper Mississagi Formation, 14 points.

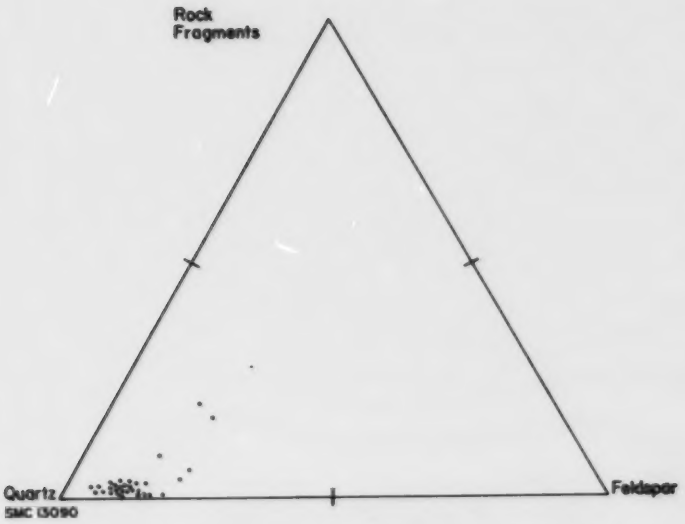

Figure 14c–Triangular diagram to show composition of sandstones with recognizable rock fragments in Mississagi Formation.

Accessory minerals, including pyrite, iron-titanium oxides, sphene, carbonate, zircon, and tourmaline, are present in minor (0.5 percent to 1 percent) amounts. Locally, pyrite in the form of disseminated crystals constitutes as much as 2 percent by volume of the rock. Several sandstone units in the lower and central parts of the Mississagi Formation are characterized by the presence of hematite which occurs as disseminations in the matrix, as grain coatings, and as concentrations along joints and fractures.

Siltstone, sandy siltstone, and argillite that occur as partings, interbeds, and units up to about 200 feet (60 m) thick, are dark grey to black and are commonly laminated or cross-laminated. These rocks consist of abundant phyllosilicates (muscovite, biotite, chlorite) and silt-size quartz and feldspars. Sand- or granule-size quartz, feldspar, and rock fragments are commonly present in amounts up to 30 percent.

Several varieties of conglomeratic rocks form discontinuous lenses seldom over a few inches (10 cm) in thickness. Pebbly mudstone lenses a few inches (10 cm) thick are common in Unit C of the Mississagi sedimentary cycles. These pebbly lenses appear to represent lag deposits formed by winnowing of the underlying sediment, and consist of small, less than ½ inch (1.3 cm) pebbles and granules of quartz and granite in a mudstone or siltstone matrix.

Quartz-pebble conglomerate lenses similar to those of the Matinenda Formation (except that they contain no, or very minor, radioactive material), are rarely present in the upper parts of the Mississagi Formation, especially in the north. The quartz-pebble conglomerate lenses are thin, less than 6 inches (15 cm), cannot be traced more than about 50 feet (15 m), and consist of small, less than

1 inch (2.5 cm), rounded quartz pebbles (30 percent to 50 percent of the volume of the rock) in a feldspathic sandstone matrix. In addition, the coarse arkose of the upper part of the formation is locally conglomeratic, containing scattered, small, less than ½ inch (1.3 cm) pebbles and granules of quartz and granite (Figures 14b and 14c).

Quirke Lake Group

BRUCE FORMATION

Lithology and Lithological Variations

The Bruce Formation, consisting mainly of sparsely pebbled polymictic paraconglomerate, is probably better termed pebbly greywacke. Interstratified units of pebbly subgreywacke and protoquartzite, feldspathic sandstone, greywacke, and siltstone are present locally. In several localities in the northern part of the report-area, thin, pebble-free greywacke lenses occur at the base. Relatively well-sorted polymictic paraconglomerate and orthoconglomerate with a subgreywacke or protoquartzite matrix locally occupies the lower few feet (2 to 50 feet; 0.6 to 15 m) of the formation. Feldspathic sandstone lenses ranging in thickness from a few inches (10 cm) to about 100 feet (30 m) are locally present in the lower and middle portions of the Bruce Formation. The conglomeratic rocks in the upper part of the formation commonly contain minor amounts of carbonate minerals, and, locally, thin lenses of calcareous siltstone and limestone lithologically similar to rocks of the overlying Espanola Formation. The contact between the Bruce Formation and the underlying Mississagi Formation is generally abrupt, but conformable. Locally, evidence exists for minor erosion of the Mississagi sandstone immediately below the Bruce conglomerate.

The Bruce Formation varies in thickness from a few tens of feet to possibly as much as 1,500 feet (460 m). The Formation has a general tendency to thin southward, and in several localities in the extreme southwest and southeast is apparently absent.

In the north, the Bruce Formation varies in thickness from 200 to 1,300 feet (60 to 400 m) and averages 500 feet (150 m). It is as much as 1,500 feet (460 m) thick in the central part of the report-area, but is mainly only 200 to 300 feet (60 to 90 m) thick. In the south, the Bruce Formation is less than 200 feet (60 m) thick, and is locally absent. Appreciable amounts of interbedded sandstone, siltstone, and greywacke usually occur in the thicker sections. For example, in the thicker sections in the central part of the report-area, feldspathic sandstone constitutes 10 to 15 percent of the Bruce Formation whereas in the thinner sections, sandstone constitutes a very small proportion of the formation.

The Bruce Formation is generally massive, unbedded, and unsorted. Locally, however, crude stratification of the conglomeratic rocks is revealed by sandstone and siltstone lenses and "wisps", and by variations in pebble size and sorting, and by variations in matrix composition.

Petrography and Chemistry

Polymictic paraconglomerate constitutes over 90 percent of the Bruce Formation, and is a dark grey, buff-weathering rock composed of plutonic igneous pebbles, cobbles, and boulders which are set in a poorly sorted sandstone matrix.

Angular to subrounded rock fragments over ½ inch (1.3 cm) in diameter constitute approximately 5 to 60 percent of the rock, but are generally present in amounts of about 15 percent. The fragments are of granitic (40 to 80 percent; average 60 percent), felsic volcanic (1 to 35 percent; average 5 percent), mafic igneous (1 to 30 percent; average 15 percent), quartz and quartzite (1 to 25 percent; average 18 percent), and pelitic metasedimentary (0 to 10 percent; average 2 percent) origin. These rock fragments range in maximum dimension from less than 1 inch (2.5 cm) to about 5 feet (1.5 m), and average about 1 inch (2.5 cm). Generally more than 90 percent of the clasts are less than 3 inches (7.6 cm) in diameter.

Typically, the matrix is a poorly sorted greywacke characterized by the presence of numerous well-rounded quartz grains approximately 1 to 5 mm in diameter. Disseminated sulphide minerals, mainly pyrrhotite and pyrite also occur. The matrix consists of angular to rounded grains of quartz (25 to 70 percent; average 45 percent), feldspars (5 to 20 percent; average 7 percent), and rock fragments (0 to 10 percent; average 3 percent), in an abundant (20 to 70 percent; average 45 percent) matrix of micas, chlorite, and silt-size quartz and feldspars (Figure 15a). The size distribution of the matrix constituents generally is distinctly polymodal (Figure 15b). The principal mode falls in the fine-sand range (0.1 to 0.25 mm) and secondary modes in the coarse sand granule range (1 to 4 mm) and clay-silt ranges. The coarser secondary mode is attributable to the rounded quartz grains and granules, the finer, to the abundant silty matrix materials. The ratio of potassic feldspar to plagioclase varies from about 10 to 0.1, and for the formation as a whole probably averages about 1. Lithic greywacke tends to have a relatively high plagioclase content; feldspathic greywacke may have either a high plagioclase or a high potassic feldspar content; and quartz greywacke and subgreywacke commonly have high potassic feldspar contents. Accessory minerals, generally present in amounts of 1 to 3 percent, include carbonate, zircon, tourmaline, epidote, sphene, and iron-titanium oxides. Pyrrhotite, pyrite, and rarely, chalcopyrite, are generally present in amounts of about 1 percent and locally in amounts up to 5 percent. Carbonate minerals, which are commonly present in amounts of 1 to 5 percent in the upper part of the formation, include dolomite and calcite. Dolomite is generally about twice as abundant as calcite. Compositionally and texturally, the conglomerate matrix is mainly feldspathic greywacke, but lithic greywacke, quartz greywacke, and subgreywacke are also present in lesser amounts.

Chemical analyses (see Table 7) show that the Bruce conglomerates have K_2O/Na_2O ratios of about 0.9, CaO/Na_2O ratios of 0.3, and Al_2O_3/Na_2O ratios of approximately 4. Comparison of these ratios with those of the Ramsay Lake and Gowganda conglomerates indicates that the Bruce rocks are intermediate in chemical maturity relative to the other two conglomeratic units.

The sandstone that occurs locally within the Bruce conglomeratic rocks is mainly moderately sorted, medium-grained feldspathic protoquartzite and sub-

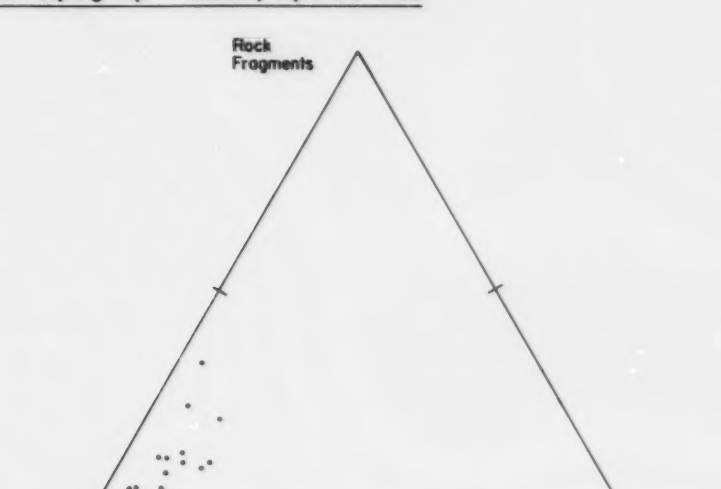

Figure 15a–Triangular diagram to show mineralogical compositions of conglomerate matrices with recognizable rock fragments in the Bruce Formation.

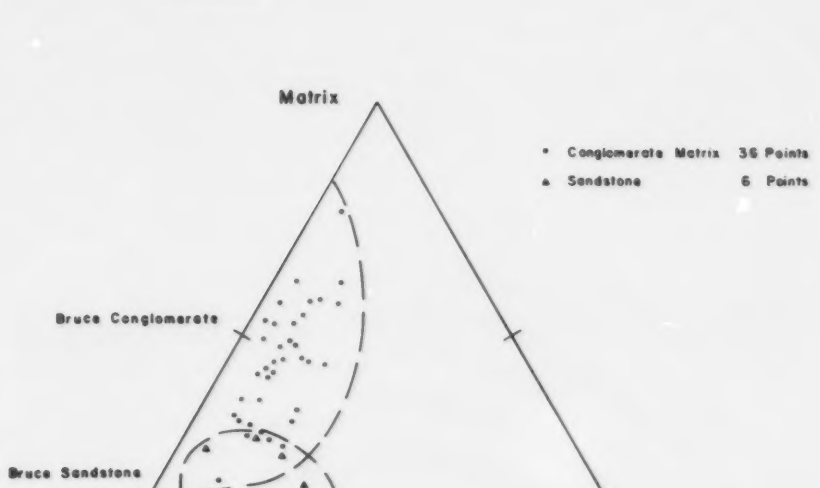

Figure 15b–Triangular diagram to show mineralogical compositions of sandstone and conglomerate in the Bruce Formation. Conglomerate matrix, 36 points. Sandstone, 6 points.

greywacke consisting of 55 percent to 75 percent quartz, 5 to 35 percent feldspars and minor rock fragments, and 10 to 30 percent matrix.

The siltstone, calcareous siltstone, and silty limestone lenses are mineralogically and texturally similar to rocks of the overlying Espanola Formation.

ESPANOLA FORMATION

Lithology and Lithological Variations

The Espanola Formation consists of siltstone, sandstone, and limestone, and is characterized by the prevalence of the carbonate minerals, calcite and dolomite. The Espanola Formation can be subdivided into three conformable members which are present throughout most of the report-area. Locally, a fourth upper member is present.

The contact between the Espanola Formation and the underlying Bruce Formation is conformable and commonly abrupt with thin-bedded silty Espanola limestone overlying Bruce conglomerate (see Section 22, Chart C, back pocket). However, many localities exist where the upper few feet (1 m) of the Bruce conglomerate contain carbonate minerals (10 to 15 percent). In McGregor Bay, units of calcareous siltstone and silty limestone occur in the upper part of the Bruce Formation, and units of polymictic conglomerate occur in the lower part of the Espanola Formation (see Section 23, Chart D, back pocket).

The lower member of the Espanola Formation varies in thickness from about 50 to 100 feet (15 to 30 m), and consists of interbedded limestone, dolostone, and calcareous siltstone (70 percent), with some (30 percent) sandstone (fine-grained greywacke and subgreywacke). The rocks of this member are notably rich in carbonate minerals, and the unit as a whole contains approximately 30 percent calcite and dolomite. In the samples analyzed, the calcite/dolomite ratio ranges from about 0.1 to 15, averages about 4; consequently calcite is the dominant carbonate.

The second member varies in thickness from about 400 to 1,000 feet (120 to 300 m), and consists of interbedded calcareous and non-calcareous siltstone and fine-grained greywacke (70 percent), silty dolostone and limestone (20 percent), and quartz sandstone (protoquartzite, subgreywacke) (10 percent). The unit as a whole contains approximately 15 percent carbonate minerals. The calcite/dolomite ratio ranges from 0.1 to 40, and on the average, calcite and dolomite are present in approximately equal proportions. The upper 150 to 250 feet (45 to 75 m) of this member generally contains appreciable, up to 50 percent by volume, silty limestone and dolostone interbeds, and, locally could be distinguished as a separate member.

The third member varies in thickness from about 200 to 700 feet (60 to 200 m) and is locally absent. It consists mainly (85 percent) of calcareous and non-calcareous medium-grained quartz sandstone (protoquartzite, subgreywacke), with interbeds of siltstone and greywacke (15 percent). These rocks locally contain up to 50 percent carbonate minerals, but the average carbonate content of the unit is only about 10 percent. Calcite is the dominant carbonate.

The upper, discontinuous member has a maximum thickness of about 50 feet (15 m), and consists of calcareous siltstone and greywacke (50 percent), silty limestone and dolostone (40 percent), and minor (10 percent) quartz sandstone. The average carbonate content of this unit is approximately 20 percent.

Locally other rock types are present within the Espanola Formation. In several localities in the south, thin conglomeratic units lithologically similar to the underlying Bruce conglomerate are present in the lower part of the Espanola Formation. In the Lake Panache area, a basal unit of black, non-calcareous argillite and siltstone up to 200 feet (60 m) thick locally is present.

There is apparently little lateral variation in the relative amounts of limestone, siltstone, and sandstone present within the various members in the central and southern parts of the report-area where the formation ranges in thickness from about 1,200 to 1,800 feet (370 to 550 m), and averages approximately 1,400 feet (430 m). However, in the north, and in the east near the Grenville Front, the formation is thinner than in the central and southern parts of the report-area, ranges from 500 to 1,000 feet (150 to 300 m) in thickness, and averages 700 feet (200 m). In the north, for example in Vernon Township the lower member contains a high proportion of pure limestone and dolostone. Sections exposing the lower member are approximately 50 to 100 feet (15 to 30 m) thick and consist almost totally of white- or buff-weathering limestone and dolostone beds which are approximately 1 inch (2.5 cm) to a foot (0.3 m) thick, with only minor (10 percent) silty interbeds. In both the northern and extreme eastern areas, the upper sandstone member is thin or absent.

Petrography

White to grey, recrystallized limestone and dolostone consist mainly of calcite and dolomite (70 to 90 percent; average 75 percent), variable amounts of sand-size quartz and feldspars (0 to 30 percent; average 20 percent) and silty material now represented mainly by phyllosilicates of metamorphic origin (0 to 20 percent; average 5 percent). Every gradation exists from limestone (dolostone) through sandy and silty limestone (dolostone) to calcareous sandstone and siltstone (Figure 16a). Differential weathering of thin, alternating carbonate-rich and silt- or sand-rich beds gives a characteristic "ribbed" weathering surface to these rocks.

Calcite is the dominant carbonate mineral. Both detrital potassic feldspar and plagioclase are present in the sandy limestone (dolostone). The potassic feldspar/plagioclase ratio of the samples studied ranges from 0.15 to 15 and averages 2 to 4. Accessory minerals include iron-titanium oxide minerals, sulphide minerals, and minor zircon and apatite.

The texture of these rocks is metamorphic, and consists of a mosaic of recrystallized carbonate and phyllosilicate minerals. Porphyroblasts of micas, chlorite, scapolite, and amphiboles are common. The sandy varieties consist of corroded grains of quartz and feldspars "floating" in a recrystallized matrix of carbonates and phyllosilicates.

Siltstone and greywacke of the Espanola Formation are grey to black, fine-grained (0.1 mm or less), poorly sorted rocks consisting of phyllosilicates, angular

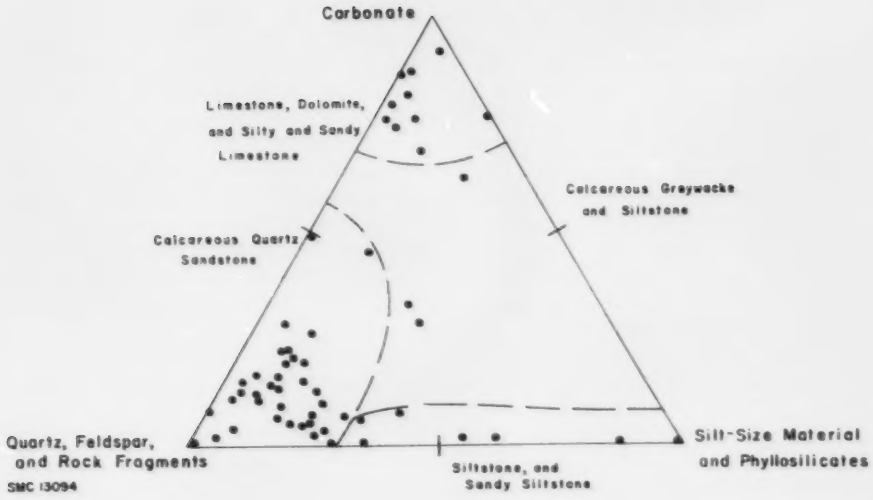

Figure 16a–Triangular diagram to show mineralogical compositions of rocks of the Espanola Formation. All positions, 55 points.

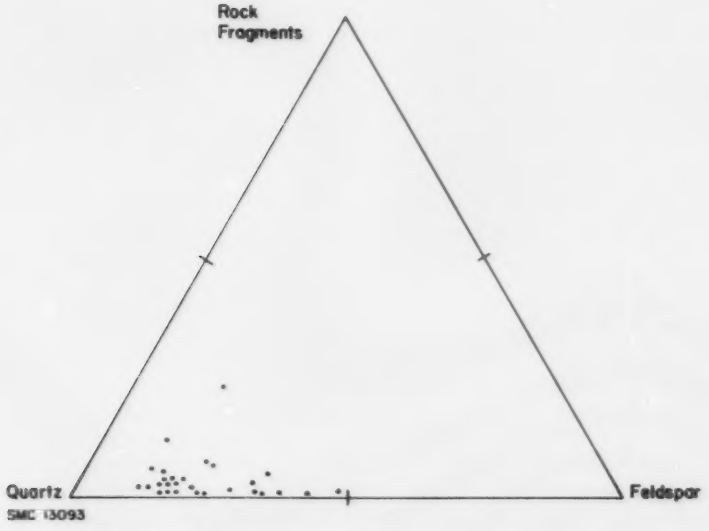

Figure 16b–Triangular diagram to show mineralogical compositions of sandstones with recognizable rock fragments from the Espanola Formation.

to subrounded grains of quartz and feldspar, and carbonates. The proportions of silty material (phyllosilicates, silt-size quartz and feldspars), sand (quartz, feldspars, rock fragments), and carbonates (dolomite, calcite) are highly variable. The proportion of silty material ranges from 30 to 100 percent and averages 40 percent, and the sand content ranges from <1 to 60 percent and averages vary from 40 to 50 percent. Carbonate minerals are present in amounts as much as 60 percent. The samples studied appear to fall into two groups; one having less than 10 percent carbonate minerals, and the other containing about 30 percent carbonates. The ratio of calcite to dolomite is variable, but on the average, the two minerals are present in about equal proportions. The ratio of potassic feldspar to plagioclase is also variable, (0.5 to 15), and averages about 3 percent. Rock fragments, mainly siltstone and shale, are present in amounts as high as 10 percent but generally constitute less than 3 percent. Minor amounts (generally less than 1 percent) of zircon, apatite, tourmaline, iron-titanium oxides, and sulphide minerals are also present.

Grey, white, and pink, poorly to moderately sorted protoquartzite and subgreywacke occur throughout the Espanola Formation, but are concentrated in the upper part. These are mainly medium-grained (0.1 to 0.5 mm) rocks consisting of subangular to subrounded grains of quartz and feldspars in a matrix of carbonate minerals and phyllosilicate minerals. Some of the beds show a distinctly bimodal grain-size distribution consisting of well-rounded grains and granules (1 to 10 mm) of quartz set in a poorly sorted, fine- to medium-grained protoquartzite or subgreywacke matrix.

Sand-size grains of quartz, feldspars, and rock fragments constitute 60 percent to 95 percent (average 70 percent) of the rock, and silty material forms as much as 30 percent (average 10 to 15 percent) of the rock (Figures 16a and b). Carbonate minerals, mainly calcite, constitute 0 to 50 percent (average 10 to 15 percent) of the rock, and form interstitial cement, disseminated patches, and euhedral crystals. The ratio of potassic feldspar to plagioclase ranges from 0.5 to 5 and averages about 4. The ratio of quartz to feldspar ranges from about 1 to 10 and also averages about 4. Rock fragments are present in amounts as high as 10 percent in some sandstone units, but generally constitute only 1 to 2 percent, and are commonly absent (Figure 16b). Siltstone forms the most abundant fragments, but in some of the upper sandstones, a few granitic fragments are present. Accessory minerals include zircon, apatite, iron-titanium oxide minerals, and sulphide minerals.

Chemistry

Chemical analyses of the main rock types in the Espanola Formation are given in Table 9. In Figure 17, plots of $CaO + MgO - SiO_2 - Al_2O_3$ indicate the proportions of the various components (carbonate, sand, silt) in each chemically analyzed rock type. Limestone and dolostone plot near the $CaO + MgO$ apex whereas silty and sandy varieties plot toward the $SiO_2 - Al_2O_3$ join. Sandstone plots near the SiO_2 apex. Siltstone and greywacke also plot near the SiO_2 apex but are shifted toward the Al_2O_3 and $CaO + MgO$ apices.

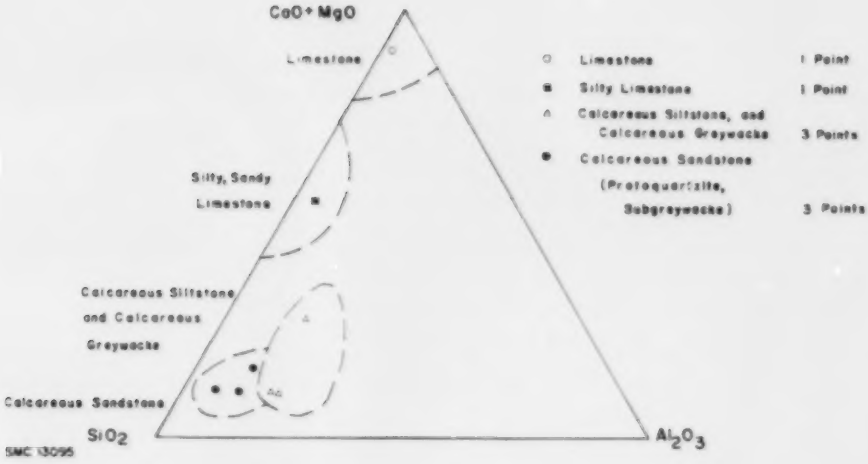

Figure 17–SiO_2—Al_2O_3—CaO diagram to show the chemical composition of analyzed rocks of the Espanola Formation.

Limestone has high (85) CaO/MgO ratios that reflect the dominance of calcite over dolomite. Dolostone probably ranges in composition from relatively pure dolostone to dolomitic limestone as indicated by the low to intermediate CaO/MgO ratios. Silty limestone exhibits low to intermediate (8) CaO/MgO ratios and calcareous siltstone (0.5) ratios which indicate the dominance of dolomite. Calcareous sandstone generally exhibits intermediate (10) CaO/MgO ratios which show the prevalence of calcite over dolomite.

SERPENT FORMATION

Lithology and Lithological Variations

The Serpent Formation comprises a sequence of feldspathic sandstone with minor siltstone and calcareous and conglomeratic rocks. The contact between the Espanola and Serpent Formations is conformable and gradational over an interval as much as several hundred feet (120 m) thick consisting of interbedded sandstone, siltstone, and silty limestone (see Section 23, Chart D, in back pocket) rocks. The thickness of the Serpent Formation is highly variable from place to place.

In the north, the Serpent Formation is up to 2,000 feet (600 m) thick, and in the south is 600 feet (180 m) to probably more than 5,000 feet (1 500 m) thick. Locally in the south the thickness of the Serpent Formation is as little as 50 feet (15 m). In the west-central part of the report-area, the Serpent Formation is 1,000 to 2,000 feet (300 to 600 m) thick, but it thins eastward toward the Grenville

Table 9 | CHEMICAL ANALYSES OF ROCKS OF THE ESPANOLA FORMATION; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH, ONTARIO DIVISION OF MINES.

	Major Components in Weight Percent																
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	CO_2	TiO_2	MnO	P_2O_5	S	Total	S.G.
(1)	4.37	0.76	0.36	0.70	0.59	51.00	0.04	0.30	...	0.14	40.50	0.05	0.32	0.22	0.06	99.41	2.72
(2)	26.15	2.71	1.60	2.48	3.91	31.56	0.84	0.80	0.66	0.01	28.25	0.11	0.22	0.06	0.05	99.39	2.79
(3)	45.50	12.50	5.82	12.55	4.65	2.13	0.57	2.34	5.53	0.70	2.22	3.65	0.17	0.15	0.02	98.50	2.68
(4)	59.30	15.60	1.09	3.98	6.80	2.42	1.70	4.92	1.11	0.05	0.82	0.53	0.03	0.12	0.27	98.74	...
(5)	73.50	9.58	...	0.55	0.56	5.35	4.10	0.80	0.18	0.06	4.40	0.14	0.08	0.03	0.02	99.35	2.64

Notes

(1) Limestone (marble), McGregor Bay.
(2) Silty limestone, Foster Township.
(3) Calcareous siltstone, Foster Township.
(4) Calcareous siltstone (scapolitic hornfels), Merritt Township.
(5) Calcareous sandstone, Mongowin Township.

Abbreviations

S.G. – Specific Gravity
... – Not determined

Front Zone to as little as 200 feet (60 m) thick. Much of the variation in thickness may be attributable to erosion that preceded or accompanied deposition of the overlying Gowganda Formation.

The Serpent Formation generally can be divided into two parts: a lower member approximately 200 feet (60 m) thick consisting of fine- to medium-grained grey feldspathic sandstone (protoquartzite, subgreywacke) with appreciable (15 percent) silty (siltstone, argillite, silty sandstone) interbeds, partings and minor disseminated carbonate minerals; and an upper member, consisting of fine- to very coarse grained feldspathic sandstone (feldspathic quartzite, arkose), with minor silty partings, and conglomeratic and carbonate-bearing units. Cyclic repetitions of thin-bedded, fine- to medium-grained sandstone and thick-bedded, medium- to very coarse grained sandstone occur in the upper part of the Serpent Formation. The carbonate-bearing units, which are 20 to 50 feet (6 to 15 m) thick, consist of interbedded calcareous siltstone, fine-grained greywacke, silty limestone, and feldspathic sandstone. The conglomeratic rocks include coarse-grained conglomeratic sandstone beds and thin polymictic orthoconglomerate and paraconglomerate lenses. A general upward increase in average grain-size and degree of sorting takes place within the formation as a whole. The sandstones in the lower part are mainly fine-grained subgreywacke and protoquartzite with more than 10 percent interstitial matrix, whereas those of the upper part are mainly medium-grained arkose and subarkose with less than 10 percent matrix. The amount of silty material in the form of interbeds, partings, and interstitial matrix generally decreases upward; although the silty units in the upper part of the Serpent Formation would represent a reversal of this general trend.

The Serpent Formation shows rapid variations in thickness from less than 100 feet (>30 m) to probably more than 5,000 feet (1 500 m). However, the only consistent trend is the rapid thinning of the Serpent Formation as the Grenville Front is approached. The carbonate-bearing units in the upper part are present only in the south; in the north a greater proportion of fine-grained feldspathic sandstone with a 'porcellaneous' weathering surface is present.

Petrography

The sandstones of the Serpent Formation are notably feldspathic, they contain on average about 30 percent feldspars. The sandstones of the lower part are mainly grey, poorly sorted, fine- to medium-grained (average 0.1 to 0.3 mm), immature to submature protoquartzite and subgreywacke consisting of angular to subrounded grains of quartz (50 to 70 percent; average 55 percent), feldspars and rock fragments (10 to 40 percent; average 25 percent) with abundant interstitial silty material (5 to 30 percent; average 20 percent) (Figure 18a). Minor amounts of carbonate (calcite, dolomite), sphene, and iron-titanium oxides are commonly present. Both potassic feldspar and plagioclase are present, with plagioclase the most abundant feldspar. Rock fragments, where present, generally constitute no more than 2 percent and are mainly siltstone and mudstone (Figure 18b).

The remaining sandstones in the Serpent Formation are mainly pink or green, moderately sorted, fine- to very coarse-grained (average 0.5 mm; range 0.1 to 2 mm)

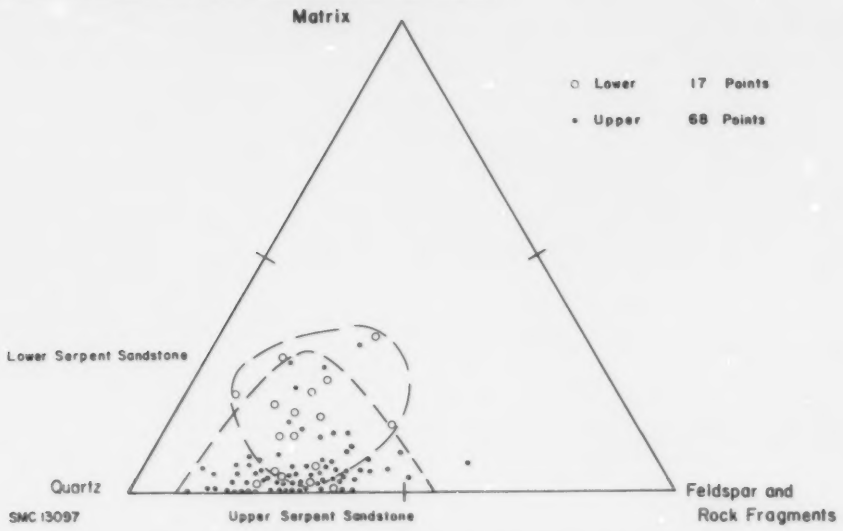

Figure 18a–Triangular diagram to show stratigraphic variation in mineralogical composition of sandstones from the Serpent Formation. 17 points from the lower part, and 68 points from the upper part.

submature feldspathic quartzite and arkose. These sandstones consist of subangular to rounded grains of quartz (45 to 90 percent; average 55 percent), feldspars and rock fragments (10 to 50 percent; average 30 percent) with interstitial silty matrix materials (0 to 30 percent; average 5 percent). The ratio of potassic feldspar to plagioclase is variable; plagioclase dominates in the lower part of the formation, and potassic feldspar in the upper part. Rock fragments, where present mainly are granitic and vein quartz in composition, and generally constitute less than 5 percent where present. Locally siltstone and mudstone fragments probably derived from the break-up of silty interbeds are abundant (10 percent).

Coarse-grained feldspathic sandstone lenses and beds with scattered granules and small pebbles (less than ½ inch; 1.3 cm) in diameter of quartz, feldspar, and granite occur throughout the upper part of the Serpent Formation. Typically, these pebble concentrations occur in the upper parts of thick, reworked feldspathic sandstone sequences on the upper surfaces of thick cross-stratified units. Such rocks probably represent lag deposits.

Thin, generally less than 3 feet (0.9 m) thick lenses of polymictic paraconglomerate and orthoconglomerate occur locally in the upper part of the Serpent Formation (see Section 22, Chart C, back pocket). These consist of 20 to 80 percent granitic, quartz, quartzite, and greenstone pebbles averaging about 1 inch (2.5 cm) in diameter in a feldspathic greywacke or subgreywacke matrix.

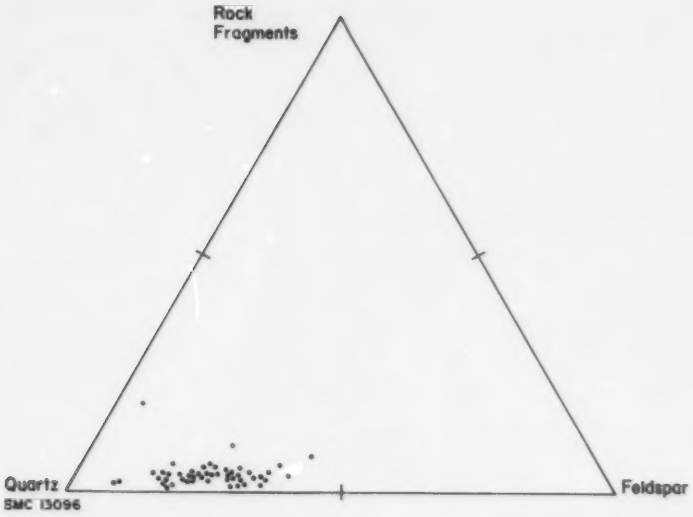

Figure 18b–Triangular diagram to show variation in mineralogical composition of sandstones with recognizable rock fragments from Serpent Formation.

Silty partings and interbeds occur throughout the Serpent Formation, but are concentrated in the lower part. These partings and interbeds consist of laminated or cross-laminated fine-grained siltstone and silty sandstone.

In the upper part of the Serpent Formation in the south, carbonate-bearing units 20 to 50 feet (6 to 15 m) thick consist of siltstone and fine-grained greywacke, with minor silty limestone and feldspathic sandstone. These rocks are lithologically similar to those of the underlying Espanola Formation.

Cobalt Group

GOWGANDA FORMATION

Lithology and Lithological Variations

The nature of the contact between the Gowganda Formation and the underlying Serpent Formation is highly variable from place to place. In Merritt and Mongowin Townships in the central part of the area, the basal Gowganda conglomerate lies directly on an irregular erosion surface developed on Serpent sand-

stone (see Section 21, Chart C, back pocket). In the Bay of Islands in the southwest of the area (see Section 25, Chart D, back pocket), the contact is again abrupt; evidence exists for beveling and erosion of probably unconsolidated Serpent sediments. Locally in the Bay of Islands area a unit of black siltstone (not shown in the sections) as much as 5 feet (1.5 m) thick occurs between the Serpent sandstone and Gowganda conglomerate. In contrast, however, in the McGregor Bay area, the contact is transitional through an interval some several tens of feet (30 m) thick consisting of interstratified sandstone and conglomerate (see Section 24, Chart D, back pocket).

The Gowganda Formation can be divided into two units of approximately equal thickness; a lower unit of cyclically repeated conglomeratic and pelitic members, and an upper unit of interbedded sandstone and pelitic rocks (see Section 22, Chart C, back pocket). These major units can in turn be subdivided into a number of lithostratigraphic members as follows:

Lower Unit

(1) Lower conglomeratic member – 300 to 600 feet (90 to 180 m) of polymictic paraconglomerate with variable amounts of sorted orthoconglomerate and sandstone.
(2) Lower argillite member – 300 to 800 feet (90 to 240 m) of siltstone, argillite, and fine-grained sandstone.
(3) Upper conglomeratic member – 200 to 800 feet (60 to 240 m) of interbedded paraconglomerate, orthoconglomerate, sandstone, and siltstone. This member can locally be subdivided into several paraconglomerate units separated by units of bedded orthoconglomerate, sandstone, and argillite.
(4) Upper argillite member – 350 to 600 feet (100 to 180 m) of argillite and siltstone characterized by slump structures.

Upper Unit

(1) Approximately 100 feet (30 m) of sandstone with siltstone interbeds.
(2) One hundred to 500 feet (30 to 150 m) of siltstone and sandstone with some calcareous siltstone interbeds.
(3) A coarsening-upward sequence some 500 to 1,000 feet (150 to 300 m) thick of feldspathic sandstone with siltstone interbeds and partings.
(4) A coarsening-upward sequence some 200 to 450 feet (60 to 140 m) thick of argillite and siltstone with increasing amounts of sandstone upward in the gradational contact zone with the overlying Lorrain Formation.

Numerous variations in this general stratigraphic sequence exist from place to place. Erosional disconformities, especially within the lower half of the Gowganda Formation, have resulted in the absence of members locally. Individual members are lensoid and variations in their lithological makeup take place from place to place. For example, the lower conglomerate member (1) in Mongowin Township and in the Whitefish Falls area consists mainly of massive, practically unstratified paraconglomerate (see Section 25, Chart D, back pocket), whereas in the McGregor Bay area this member contains appreciable amounts of bedded orthoconglomerate and sandstone (see Section 24, Chart D, back pocket).

The total thickness of the Gowganda Formation varies from place to place, and in general appears to thin southeastward. In Mongowin Township, the average

thickness of the Gowganda Formation is about 4,000 feet (1 200 m). Around Whitefish Falls on the North Shore of Lake Huron it is 3,200 to 3,800 feet (970 to 1 150 m) in thickness, and to the east in McGregor Bay, about 2,800 to 3,200 feet (850 to 970 m). In Eden Township near the Grenville Front Zone, it is apparently only 600 to 1,800 feet (180 to 540 m) thick and consists mainly (90 percent) of siltstone, greywacke, and sandstone with minor amounts of conglomeratic rocks.

Petrography

Several types of conglomeratic rocks are present in the Gowganda Formation. Polymictic paraconglomerate (diamictite, pebbly mudstone) is common in the lower and middle parts of the formation. Polymictic orthoconglomerate occurs mainly as lenses and beds in the middle of the formation, but is also locally abundant at the base.

Polymictic paraconglomerate is an unsorted, pebbly muddy sandstone consisting of plutonic rock fragments in a silty sandstone (greywacke) or sandy siltstone matrix. The matrix is generally massive and unstratified although locally it is bedded or laminated. Angular to rounded rock fragments, ranging in maximum dimension from less than 1 inch (2.5 cm) to about 15 feet (4.5 m) and averaging 2 to 3 inches (5 to 7.5 cm), constitute 5 to 30 percent (average 15 percent) of the rock. The fragments are mainly of granitoid composition (80 percent), but felsic volcanic (5 percent), mafic igneous (10 percent), and metasedimentary (5 percent) varieties are also present. Rock fragments are generally unsorted with regard to size and rounding. Locally, the paraconglomerate is poorly sorted, with poorly developed bedding or laminations and uniform pebble size present in it.

The paraconglomerate matrix is generally a massive, poorly sorted, silty feldspathic greywacke. The grain size distribution is commonly polymodal, with the principal mode in the fine sand range (0.1 to 0.2 mm) and minor modes in the clay-silt and fine gravel (4 to 16 mm) grades. The greywacke matrix is composed of angular to subrounded grains of quartz (25 to 50 percent; average 40 percent), feldspar and rock fragments (5 to 65 percent; average 15 percent), and interstitial matrix (micas, chlorite, silt-size quartz and feldspar) (35 to 80 percent; average 45 percent) (Figures 19a, b). Locally, the matrix is a better sorted quartz greywacke, subgreywacke or protoquartzite with abundant rounded quartz grains and granules. The better sorted matrix consists of quartz (15 to 70 percent; average 65 percent), feldspars and rock fragments (15 to 65 percent; average 25 percent), and has distinctly less interstitial matrix (10 to 30 percent; average 20 percent). Sand-size rock fragments, which are mainly granitic, mafic igneous, and metasedimentary types, are present in amounts up to 25 percent but commonly constitute less than 10 percent of the rock. The ratio of potassic feldspar to plagioclase is generally low (0.1 to 4), and in general the two feldspars are present in about equal proportions.

Polymictic orthoconglomerate contains a higher proportion of rock fragments (50 to 80 percent) and is generally better sorted than the paraconglomerate. The pebbles, ranging from less than 1 inch (2.5 cm) to about 2 feet (0.6 m) and averaging about 1 to 2 inches (2.5 to 5.0 cm) in diameter, are of relatively uniform

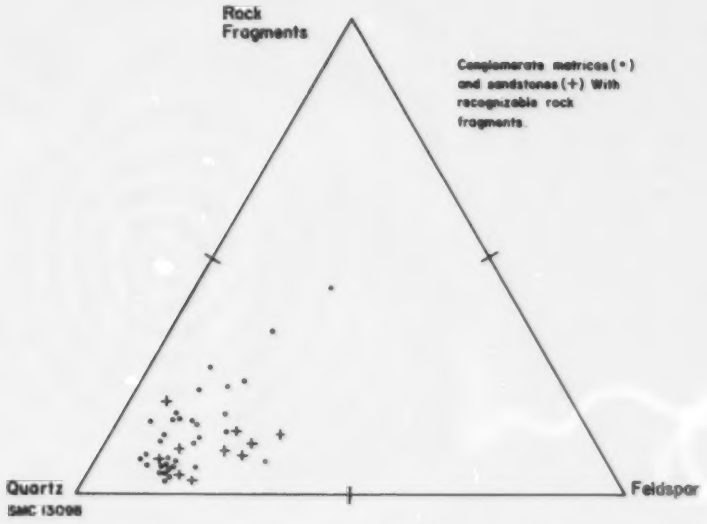

Figure 19a–Triangular diagram to show composition of conglomerate matrices and sandstones with recognizable rock fragments, Gowganda Formation.

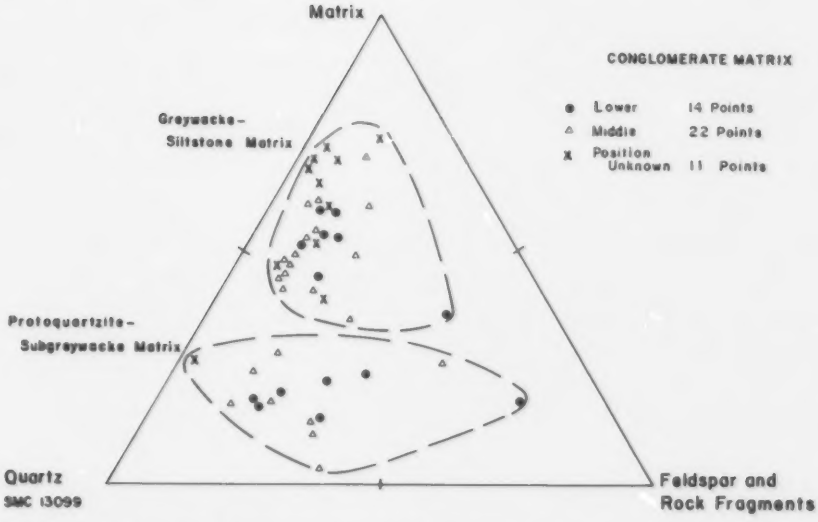

Figure 19b–Triangular diagram to show variation in mineralogical composition of conglomerate matrices, Gowganda Formation.

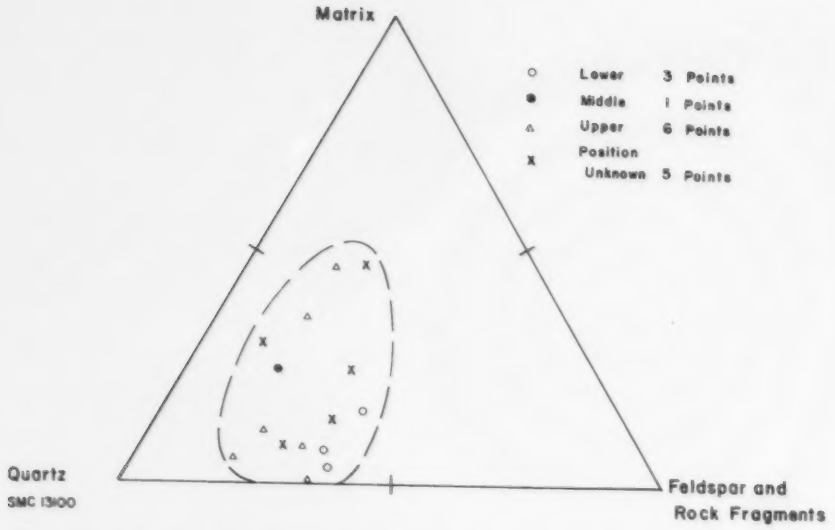

Figure 19c–Triangular diagram to show stratigraphic variation in mineralogical composition of sandstone, Gowganda Formation.

size in any one bed, and are generally subrounded to rounded. The pebbles mainly have a mineralogical composition of granitic rocks, vein quartz, mafic and felsic volcanic rocks, and metasediments. The matrix is mainly medium-grained quartz greywacke and subgreywacke. The matrix is generally better sorted than the paraconglomerate matrix, has a lower proportion of silty matrix, and a higher quartz/feldspar ratio.

Accessory minerals in the conglomeratic rocks include iron-titanium oxide minerals, sulphide minerals, sphene, and zircon. Locally, carbonate minerals, dolomite, calcite, and ankerite, are present in amounts up to about 2 percent.

Pelitic members, which here include argillite, siltstone, and fine-grained silty greywacke, occur throughout the Gowganda Formation as members, interbeds, and partings. Pelitic rocks mainly occur in the lower half and at the top of the formation.

Two main types of pelitic rocks are present, regularly laminated siltstone and mudstone, termed 'laminated argillite', and irregularly laminated siltstone, silty sandstone, and mudstone. The laminated argillite consists of parallel, varve-like, alternating dark- and light-coloured laminae or thin beds ranging in thickness from about 1 to 10 mm. Generally, laminated argillite is not a typical varved sedimentary rock consisting of continuous couplets of graded silt and clay laminae, but rather the silt and clay are segregated into distinct layers. The grain size of the silty laminae averages about 0.03 mm and ranges up to fine-sand size. The grain size of the dark laminae averages less than 0.01 mm.

The irregularly laminated argillite consists of wavy or irregular, alternating light and dark silty and muddy laminae or thin beds ranging in thickness from about 1 to 50 mm. Numerous lenses of quartz-rich, fine-grained silty sandstone and siltstone also occur. These lenses are generally ½ to 2 inches (1.3 to 5.0 cm) thick and 3 to 12 inches (7.5 to 30 cm) long. The irregularly laminated argillite shows excellent graded beds, ripples, cross-laminations, and convolute laminations.

The pelitic rocks consist of variable proportions of muscovite, biotite, chlorite, and angular, silt to fine-sand size quartz and feldspar grains. In the dark 'muddy' laminae phyllosilicates predominate whereas, in the light silty or sandy laminae, quartz and feldspar are dominant. Accessory minerals include iron-titanium oxide minerals, sulphide minerals, and sphene. In the lower argillite member, magnetite is present in amounts up to 5 percent making this unit magnetically responsive. Carbonate is present in some siltstone beds in the upper half of the Gowganda Formation, and locally dolomite and calcite constitute up to 15 percent of the rock.

Quartz-feldspar sandstones, present throughout the Gowganda Formation, are concentrated in the upper half of the formation where they constitute the dominant lithology. These rocks are poorly to moderately sorted, medium-grained (0.1 to 0.3 mm) feldspathic sandstones ranging from feldspathic greywacke to arkose. Quartz-feldspar sandstones consist of quartz (30 to 70 percent; average 55 percent), feldspars and rock fragments (10 to 40 percent; average 25 percent), and interstitial matrix (1 to 50 percent; average 20 percent) (Figure 19c). The ratio of potassic feldspar to plagioclase is variable from about 0.2 to 4, and on the average, the two are present in about equal amounts. The quartz/feldspar ratio averages about 3. Rock fragments, mainly siltstone and schist with some granitic and mafic igneous clasts, are locally present in amounts up to 15 percent but generally average less than 5 percent.

Chemistry

Chemical analyses of Gowganda conglomerate matrices and argillites are given in Table 10. The pelitic rocks are depleted in SiO_2 and CaO, and enriched in Al_2O_3, total iron, and MgO relative to both the conglomerate matrix and to the average Archean Shield composition of northwestern Ontario (Shaw *et al.* 1967). The conglomerate matrices are chemically similar to the average shield composition, but do show relative enrichment in total iron and MgO, and depletion in CaO. The Al_2O_3/Na_2O ratio of the argillite averages about 6 and of the conglomerate matrix about 4. The CaO/Na_2O ratios are 0.4 and 0.35 respectively, and the K_2O/Na_2O ratios about 2.5. The FeO/Fe_2O_3 ratios of the argillites and conglomerate matrices analyzed range from 1 to 2 and average about 1.5.

Table 10 | CHEMICAL ANALYSES OF ROCKS OF THE GOWGANDA FORMATION.

	Major Components in Weight Percent																
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	H_2O^-	CO_2	TiO_2	MnO	P_2O_5	S	Total	S.G.
(1)	51.20	21.90	2.40	5.76	5.92	0.40	5.14	2.63	3.93	0.23	0.06	0.95	0.07	0.14	<0.01	100.74	n.d.
(2)	60.40	19.40	3.42	4.94	2.70	0.65	2.33	3.01	3.47	0.18	0.20	0.73	0.11	0.14	0.01	101.69	n.d.
(3)	59.10	16.50	4.69	5.31	3.21	1.55	2.91	2.98	2.63	0.15	0.25	0.82	0.13	0.15	0.04	100.42	2.80
(4)	57.76	17.82	2.87	4.96	4.16	1.22	3.15	3.36	3.19		...	0.75	0.00	0.23	...	99.47	n.d.
(5)	65.14	14.80	3.68	3.69	3.56	1.50	4.39	1.72	2.73		...	0.60	...	0.16	...	101.97	n.d.
(6)	66.30	15.37	1.26	2.85	2.05	3.97	3.87	2.25	0.87		...	0.47	0.07	0.13	...	99.46	n.d.

Notes

(1) Laminated siltstone-argillite, McGregor Bay.
(2) Laminated siltstone-argillite, McGregor Bay.
(3) Laminated siltstone-argillite, Mongowin Township.
(4) Laminated argillite, average of nine (Young 1969).
(5) Paraconglomerate matrix, average of 16 (Young 1969).
(6) Average Archean Shield of N.W. Ontario (Shaw *et al.* 1967).

Chemical analyses of samples 1, 2, and 3 by Mineral Research Branch, Ontario Division of Mines.

Abbreviations

S.G. – Specific Gravity
n.d. – Not determined
... – Not detected

LORRAIN FORMATION

Lithology and Lithological Variations

Quartz-rich sandstones of the Lorrain Formation are exposed in the southern part of the report-area where they form a series of rugged hills and several long peninsulas along the North Shore of Lake Huron. The contact with the underlying Gowganda Formation is conformable and gradational over a narrow stratigraphic interval; it comprises interbedded sandstone and siltstone.

The Lorrain Formation is approximately 5,000 to 8,000 feet (1,500 to 2,400 m) thick and consists almost totally of sandstone with very minor amounts of siltstone and conglomerate in the lower half. The formation can be subdivided into a number of conformable lithostratigraphic members as follows (see Section 26, Chart D, back pocket):

(1) Lower Pink and Grey Sandstone Member – 200 to 500 feet (60 to 150 m) of fine- to medium-grained feldspathic sandstone, grey silty sandstone, and interbedded siltstone.
(2) Feldspathic Sandstone Member – 500 to 1,200 feet (150 to 370 m) of coarse-grained feldspathic sandstone with some pebbly sandstone.
(3) Green Micaceous Sandstone Member – 600 to 2,000 feet (180 to 600 m) of medium- and coarse-grained micaceous, feldspathic sandstone.
(4) Hematite Sandstone Member – up to 1,800 feet (550 m) of medium-grained buff-weathering micaceous orthoquartzite characterized by the presence of clay minerals (or metamorphic equivalents) and by minor amounts of hematite. Thin conglomerate lenses are also present.
(5) White Aluminous Sandstone Member – 1,000 to 2,000 feet (300 to 600 m) of medium-grained white orthoquartzite characterized by the presence of clay minerals (kaolinite) and metamorphic minerals such as pyrophyllite, kyanite, and andalusite.
(6) Upper Orthoquartzite Member – very pure white and reddish fine-grained orthoquartzite.

The textural and mineralogical maturity of the Lorrain sandstones generally increase from the bottom to the top of the formation. The average grain size of the Lorrain sandstones increases rapidly in the lower part of the Lorrain Formation from about 0.2 to 0.5 mm, then decreases gradually to about 0.1 mm in the uppermost member. The feldspathic sandstones in the lower part of the Lorrain Formation are poorly to moderately sorted, the micaceous sandstones of the central parts are moderately sorted, and the orthoquartzites of the upper part of the Lorrain Formation are well sorted. Similarly, the detrital quartz and feldspar grains show increasing roundness upwards in the Lorrain Formation. The amount of feldspar decreases upward and in the middle of the Lorrain Formation disappears entirely and its place is taken by kaolinite (or its metamorphic equivalents). Minor amounts of hematite appear in the sandstone at about the same stratigraphic level. These mineralogical changes may record a change in conditions from rigorous, essentially mechanical weathering, possibly in a frigid regime, to chemical weathering, possibly in a tropical climate.

The Lorrain Formation is a thick, blanket-like sand deposit, which, within the relatively limited area of study, shows little in the way of thickness or lithological

variations. The hematitic sandstone member cannot be distinguished from the white aluminous sandstone member locally, but since the only difference between the two consists of a variation of about 1 percent hematite, this is not surprising.

Petrography and Chemistry

The feldspathic sandstones of the lower part of the Lorrain Formation are poorly to moderately sorted arkose, feldspathic protoquartzite and subgreywacke, and greywacke; their grain-size ranges from fine- to medium-grained in the lower member, to coarse- and very coarse grained in the second member (Figure 20a). These rocks consist of subangular and subrounded grains of quartz (30 percent to 75 percent; average 60 percent), feldspars and rock fragments (5 to 45 percent; average 20 percent) in a micaceous silty matrix (0 to 60 percent; average 20 percent). Rock fragments, including granite, siltstone, chert, and quartzite, are generally present in amounts of less than 5 percent but locally constitute up to about 20 percent (Figures 20a and 20b). Granules and small (less than ½ inch; 1.3 cm) pebbles of granite, quartz, and feldspar are abundant in pebbly arkose of the second member. The quartz/feldspar ratio varies from about 1 to 5 and averages about 2. The potassic feldspar/plagioclase ratio ranges from about 0.2 to 10 and averages 1 or 2. Accessory minerals include iron-titanium oxide minerals, zircon, tourmaline, and apatite. A chemical analysis of a typical feldspathic sandstone of the Lorrain Formation is given in Table 11.

Sandstone of the green micaceous member is a coarse- to medium-grained, moderately sorted rock consisting of subangular to subrounded grains of quartz (60 to 85 percent; average 65 percent), feldspars and rock fragments (0 to 20 percent; average 10 to 15 percent) in a micaceous matrix (5 to 30 percent; average 15 to 20 percent). Rock fragments, if present, generally constitute less than 5 percent. Feldspars are present in amounts of 5 to 15 percent in the lower two-thirds of the member, but are absent in the upper part. The quartz/feldspar and potassic feldspar/plagioclase ratios of the feldspar-bearing sandstones average about 8 to 10 respectively.

The sandstones of the hematitic, aluminous, and upper orthoquartzite members are medium- to fine-grained, well-sorted rocks consisting of rounded grains of quartz (70 to 95 percent) in a micaceous matrix (0 to 30 percent). Authigenic quartz cement is present in the upper member in amounts of 5 to 10 percent. Rock fragments are generally absent, and where present in minor amounts are mainly chert and quartzite. Minor amounts (1 or 2 percent) of hematite occur in the hematitic sandstone member as coatings on quartz grains, as streaks and spots in the matrix materials, and as concentrations along joints, fractures, and foreset surfaces of crossbeds.

Chemical analyses (Table 11) of the fine-grained upper orthoquartzite show that it consists mainly of silica and contains only minor amounts of other oxides.

Conglomeratic rocks occur as thin, 1-inch to 1-foot (2.5 cm to 0.3 m) thick lenses in the middle part of the formation. These consist of 30 to 70 percent quartz, chert, and jasperoid pebbles averaging about ½ inch (1.3 cm) in diameter in a micaceous sandstone matrix.

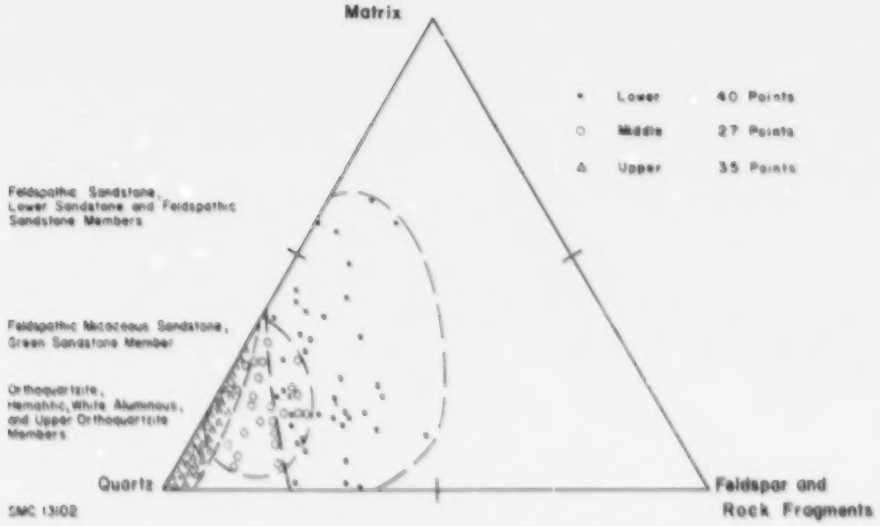

Figure 20a–Triangular diagram to show stratigraphic variation in mineralogical composition of sandstones from the Lorrain Formation.
Member 1–Lower Sandstone Member.
Member 2–Feldspathic Sandstone Member.
Member 3–Green Sandstone Member.
Member 4–Hematitic Sandstone Member.
Member 5–White Aluminous Sandstone Member.
Member 6–Upper Orthoquartzite Member.

GORDON LAKE FORMATION

Lithology and Lithological Variations

The Gordon Lake Formation is exposed in the southern part of the report-area in the axial zone of the La Cloche Syncline, and along the shores of Narrow Bay and Killarney Bay (see Section 27, Chart D, in back pocket). The contact with the underlying Lorrain Formation is conformable and gradational over a stratigraphic interval that is 30 feet (9 m) thick and consists of interbedded fine-grained silty sandstone and siltstone with abundant ripples. The Gordon Lake Formation consists of 1,800 to about 2,500 feet (550 to 760 m) of fine-grained grey,

Figure 20b–Triangular diagram to show composition of sandstones with recognizable rock fragments, Lorrain Formation.

pink, brown, black, buff, and green sandstone and siltstone. The formation can be subdivided into three intergradational units:

(a) A lower upward-fining sequence of interbedded sandstone (60 percent) and siltstone (40 percent) some 300 feet (90 m) thick.

(b) A middle siltstone (70 percent) sandstone (30 percent) sequence 1,200 to 1,900 feet (370 to 580 m) thick.

(c) An upper, upward-coarsening sandstone (70 percent) – siltstone (30 percent) sequence about 300 feet (90 m) thick which passes gradationally into sandstone of the overlying Bar River Formation.

Within the report-area, no consistent variations in total thickness or lithological makeup were observed. Compared with areas to the north (Flack Lake and Maple Mountain areas), the Gordon Lake Formation in the report-area probably contains a higher proportion of sandstone and argillaceous siltstone. Also, minerals such as gypsum and anhydrite, present in minor amounts in the north (Eisbacher and Bielenstein 1970), are apparently absent in the south. This, however, may be caused by the relatively greater degree of metamorphism of the rocks in the south and consequent destruction of these minerals.

Petrography and Chemistry

Grey, white, pink, and greenish sandstones of the Gordon Lake Formation are mainly fine-grained (0.05 to 0.2 m), poorly sorted, silty rocks composed of

Table 11 | CHEMICAL ANALYSES OF ROCKS OF THE LORRAIN AND GORDON LAKE FORMATIONS; CHEMICAL ANALYSES BY MINERAL RESEARCH BRANCH ONTARIO DIVISION OF MINES.

	Major Components in Weight Percent																
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	CO_2	TiO_2	MnO	P_2O_5	S	Total	S.G.
(1)	87.80	7.48	0.55	0.28	0.37	0.33	0.09	2.16	0.48	0.07	0.35	0.05	0.01	0.01	0.01	100.00	2.75
(2)	95.96	2.73	0.35	...	...	...	0.26	0.21	...	0.11	...	0.03	...	0.01	...	99.66	2.72
(3)	68.60	16.90	2.79	0.83	2.42	0.10	0.40	5.56	1.51	0.16	0.05	0.63	0.01	0.06	0.02	99.90	2.73

Notes

(1) Feldspathic sandstone, lower Lorrain Formation, McGregor Bay.
(2) Fine-grained orthoquartzite, upper Lorrain Formation, Curtin Township.
(3) Siltstone, Gordon Lake Formation, Curtin Township.

Abbreviations

S.G. – Specific Gravity
... – Not detected

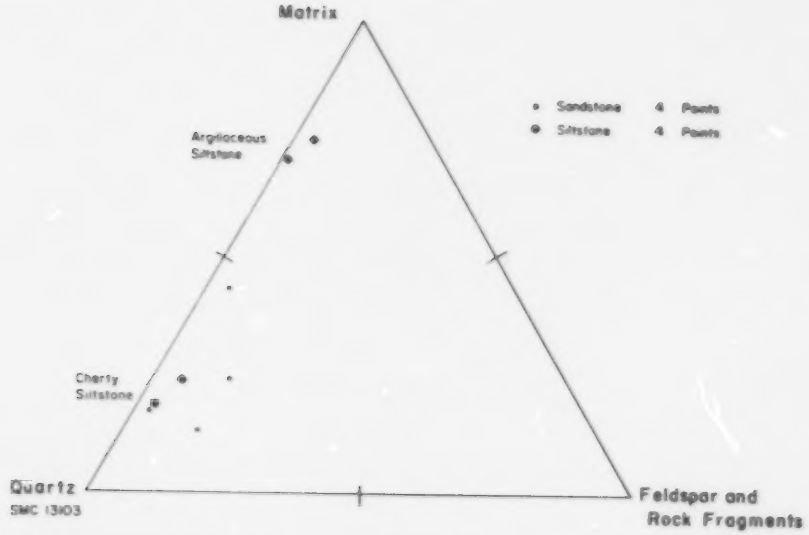

Figure 21–Triangular diagram to show mineralogical composition of siltstones in the Gordon Lake Formation.

subangular grains of quartz (55 to 75 percent; average 70 percent), and feldspars and rock fragments (5 to 15 percent; average 5 percent) in a silty matrix (10 to 45 percent; average 25 percent) of micas and chlorite (Figure 21). Accessory minerals include tourmaline, sphene, leucoxene, and iron-titanium oxides. Carbonate cement is present in some beds in amounts up to about 5 percent. Locally, magnetite is present in amounts of 2 percent to 3 percent rendering the Gordon Lake Formation magnetically responsive. Rock fragments are mainly fine-grained cherty siltstone and argillite, probably derived from break-up of silty interbeds. Potassic feldspar and plagioclase are present; potassic varieties predominate over plagioclase.

Siltstone of the Gordon Lake Formation represents variable mixtures of silt-, clay- (now represented by phyllosilicates), and minor sand-size material. Two main types are present:

(1) Argillaceous siltstone. A poorly sorted rock consisting of silt with variable proportions of clay and, commonly, minor fine sand. The argillaceous siltstones analyzed consist of quartz (20 to 30 percent), feldspar and rock fragments (0 to 5 percent), with abundant (70 to 80 percent) phyllosilicates, and, locally, minor (2 percent) carbonate cement.

(2) Cherty siltstone. A rock composed of very fine silt-size, well-sorted grains of quartz (65 to 70 percent) and minor feldspar (5 percent) with appreciable phyllosilicates (20 to 25 percent). The creamy, black, and greenish cherty siltstones occur as thin, ½ to 2 inches (1.3 to 5.0 cm) beds and as "chert breccia" beds consisting of angular to rounded cherty siltstone chips in a silty or sandy matrix.

A chemical analysis of a laminated argillaceous siltstone of the Gordon Lake Formation is given in Table 11. Megascopically, this rock is similar to "laminated argillites" of the Gowganda and McKim Formations, but chemically it is poorer in Al_2O_3, total iron, CaO, Na_2O, and K_2O. The ratios Al_2O_3/Na_2O, CaO/Na_2O, and K_2O/Na_2O for the Gordon Lake sample are 40, 0.25, and 14 respectively. Its FeO/Fe_2O_3 ratio is about 0.3. In comparison, the FeO/Fe_2O_3 ratios of Gowganda argillites range from about 1 to 2 and average 1.5, and of McKim argillites range from 1 to 4 and average 2.5. This upward transition in the Huronian sequence from ferrous iron-rich to ferric iron-rich argillaceous rocks corresponds to the appearance of hematite in the upper sandstone formations. It also demonstrates that the generally high FeO/Fe_2O_3 ratio of rocks of the lower part of the sequence is an original characteristic and is not caused by metamorphic reduction of iron.

BAR RIVER FORMATION

Lithology and Lithological Variations

The Bar River Formation is exposed in the southeastern part of the area on Frazer Point, on a series of islands in Lake Huron extending southwestward from Killarney, and on Manitoulin Island at Sheguiandah (see Section 28, Chart D, back pocket). The contact with the underlying Gordon Lake Formation is conformable and gradational through an interval 150 feet (46 m) thick consisting of interbedded siltstone and sandstone. The Bar River Formation is at least 3,000 feet (900 m) thick and can be subdivided into several lithological units:

(a) Approximately 300 feet (90 m) of white and reddish orthoquartzite with minor (10 percent) silty interbeds and partings near the base.

(b) Six hundred feet (180 m) of white orthoquartzite with very minor disseminated hematite and hematitic siltstone chips in some beds.

(c) Seven hundred and fifty feet (200 m) of hematitic and white orthoquartzite.

(d) Several cyclically repeated, upward-coarsening units consisting of a lower siltstone-sandstone portion and an upper sandstone portion. The lower silty parts of the cycles are generally 30 to 100 feet (9 to 30 m) thick and are characteristically rich in hematite. The upper sandstone portions are generally 100 to 250 feet (30 to 75 m) thick and consist of micaceous sandstone and white and hematitic orthoquartzite. The uppermost sandstone unit is approximately 600 feet (180 m) thick and consists of white and hematitic orthoquartzite.

Petrography and Chemistry

White and reddish orthoquartzite of the Bar River Formation is lithologically similar to orthoquartzite of the upper part of the Lorrain Formation. The orthoquartzite is a well-sorted, white, buff, or light grey rock composed mainly of; fine- to medium-grained (0.1 to 0.3 mm) rounded quartz (95 percent) grains; recrystallized silica cement; minor muscovite and hematite; accessory zircon, tourmaline, and monazite (Figure 22). Locally, as on Manitoulin Island, minor amounts of

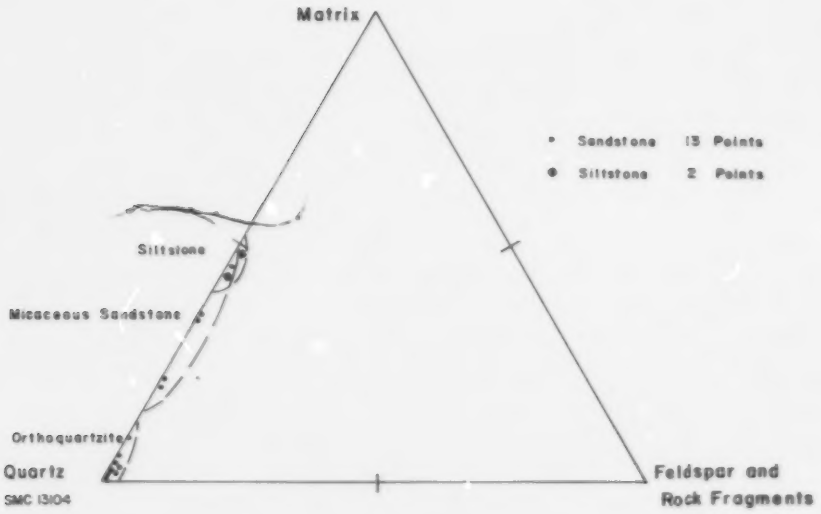

Figure 22–Triangular diagram to show mineralogical composition of rocks in the Bar River Formation.

chlorite, talc, and amphibole are present. Hematite occurs as grain coatings and as disseminations along bedding planes. Minor amounts of polygranular rock fragments (orthoquartzite and recrystallized chert) are also present locally.

Chemical analyses of orthoquartzite from the Sheguiandah Quarry given by Hewitt (1963, p.14) show that the rock consists of more than 98 percent SiO_2 and contains only minor amounts of other oxides.

Micaceous sandstones are moderately sorted rocks composed of variable proportions of fine- to medium-grained quartz (55 to 80 percent) with very minor (0 to 0.5 percent) feldspar, and micaceous minerals, (30 to 45 percent) mainly muscovite with lesser amounts of chlorite and talc. Hematite is commonly present, and in the upper part of the Bar River Formation, constitutes 5 to 10 percent of the iron-rich sandstone beds.

Siltstone of the Bar River Formation is characteristically rich in hematite and a sample from a hematite-rich bed was found to contain 16.7 percent Fe_2O_3 upon assay (Assay by Mineral Resources Branch, Ontario Division of Mines). The siltstone consists mainly of subangular to subrounded silt-size grains of quartz and minor feldspar with abundant (50 percent) micaceous minerals, including muscovite, chlorite, and biotite, and variable amounts of hematite.

STRATIGRAPHIC SECTIONS

In this report, locations, brief summaries, and generalized section diagrams are given for the measured stratigraphic sections. More complete section descriptions with details on stratigraphy, lithology, and sedimentary structures are

available in OFR5107 (Card *et al.* 1974).

The section locations are given in the inset map in Charts A, B, C, and D (back pocket), and for further information on the distribution of the various formations described, the reader is referred to Map P.668, Panache Lake West, and Map P.669, Panache Lake East published by the Ontario Division of Mines in 1971.

Section locations were selected on the basis of accessibility and outcrop density to give as wide vertical and lateral coverage as possible. Sections locations were chosen to eliminate, insofar as possible, the effects of structural complexity. Corrections were made for dip of the strata, but the area is structurally complicated and whereas obvious structural complexities were avoided or noted and taken into account, other complexities such as unrecognized faults and tectonic thickening have undoubtedly introduced errors. It is our opinion, however, that the true thickness of stratigraphic units is of less importance than their relative thickness and position.

The sections were measured by two methods; the thicknesses of formations and members were measured by simultaneously locating contacts in the field and on aerial photographs and making corrections for dip of the strata and photographic distortion; the thicknesses of beds and of selected stratigraphic intervals, especially those encompassing formational contacts, were measured with a 100-foot (30 m) long tape. Continuity of outcrop was maintained, insofar as possible, by working in a strip 100 to 200 feet (30 to 60 m) wide along each section line.

SECTION 1

Elsie Mountain and Stobie Formations, Waters Township

The section is located along the electric power transmission line in lot 9, concession V, Waters Township.

This section extends southward from the intrusive contact of the Creighton Pluton and includes some 5,000 feet (1,500 m) of interstratified mafic metavolcanics, greywackes, and pelitic metasediments of the basal Huronian metavolcanic sequence.

The Elsie Mountain Formation forms the lower 3,000 feet (900 m) of the sequence. The formation consists of thick, 75 to 350 feet (25 to 105 m), mafic flows probably with intrusions; and minor thin 40 to 60 feet (12 to 18 m) aluminous staurolite-bearing pelite and greywacke intercalations. A thin, 30 feet (9 m), porphyritic granitic dike cuts the metavolcanics near the central part of this lower unit. Amygdules are common in some flows and are concentrated near flow tops. Pillow-like structures were observed in several flows.

The upper part of the section, the Stobie Formation, consists of thin to moderately thick flows 20 to 150 feet (6 to 45 m) with appreciable amounts of interflow greywacke and siltstone. Some of these interstratified metasediments contain up to 10 percent sulphides as disseminations on fracture and joint surfaces, and locally as thin, ⅛-inch (0.3 cm) thick, stratiform layers.

SECTION 2

Stobie, Copper Cliff, McKim and Ramsay Lake Formations, Western Waters Township

The section is located north of Highway 17 in lot 10, concession III, IV, and V, Waters Township.

This section includes the following: some 3,600 feet (1,100 m) of mafic metavolcanics and interflow metasediments of the Stobie Formation; 800 feet (240 m) of felsic flows and pyroclastic rocks of the Copper Cliff Formation; 2,500 feet (760 m) of metamorphosed greywacke, siltstone, laminated argillite and minor feldspathic sandstone of the McKim Formation; and 30 feet (9 m) of coarse pebbly sandstone of the Ramsay Lake Formation.

The Stobie Formation comprises thin to moderately thick mafic metavolcanic flows, commonly with amygdaloidal and pillowed sections, and numerous metasedimentary intercalations, many of which contain appreciable amounts of disseminated sulphides. The Copper Cliff Formation consists of a lower section of felsic flows with well-developed flow layering and an upper unit of felsic pyroclastic rocks.

The McKim Formation consists of greywacke, laminated siltstone and argillite, and feldspathic sandstone. Sedimentary structures including graded beds, ripple-drift cross-laminations, Bouma cycles and slump structures are common. Numerous clastic (greywacke) dikes occur within the McKim Formation.

Conglomeratic sandstone of the Ramsay Lake Formation consists of small well rounded quartz granules and pebbles in a massive greenish sandstone matrix.

Sudbury-type breccia occurs throughout the section.

SECTION 3

Elsie Mountain and Stobie Formations, Central Graham Township

The section is located in lots 3 and 4, concession III, IV, and V, Graham Township.

This section extends southward from the intrusive contact of the Creighton Quartz Monzonite Pluton through some 7,400 feet (2,250 m) of mafic metavolcanics, minor felsic metavolcanics, and interflow metasediments, including greywacke, siltstone, quartz-rich sandstone, and sulphide-bearing sedimentary rocks. The lower 1,500 feet (460 m) of the section, the Elsie Mountain Formation, consists mainly of thick or very thick, coarse-grained, commonly porphyritic mafic flows with minor interflow metasedimentary units, including staurolite metapelites. The upper 5,700 feet (1,740 m) of the sequence, the Stobie Formation, consists of thin to moderately thick, commonly amygdaloidal mafic flows with abundant interflow sedimentary rocks including greywacke, siltstone, protoquartzite and sulphide-bearing sedimentary rocks.

SECTION 4

Elsie Mountain, Stobie and Lower McKim Formations, Central Graham Township

The section is located north of the Canadian Pacific Railway in lots 7 and 8, concession III and IV, Graham Township.

This section includes some 4,500 feet (1 400 m) of interstratified mafic metavolcanics, greywacke, and pelitic metasediments of the basal Huronian metavolcanic sequence and approximately 3,200 feet (980 m) of greywacke, pelite, and feldspathic sandstone of the McKim Formation.

The lower 750 feet (230 m) of the metavolcanic sequence, the Elsie Mountain Formation, consists of thin to moderately thick flows (probably with mafic intrusions) with some aluminous staurolite-bearing pelite and sandstone. The upper part, the Stobie Formation, comprises some 3,800 feet (1 200 m) of thin flows with appreciable amounts of greywacke and siltstone, some units of which contain disseminated sulphides. Amygdules are common in the flows and deformed pillow-like structures are present locally.

The McKim Formation consists mainly of greywacke and laminated siltstone which show the graded bedding, ripple, drift cross-laminations, and Bouma cycles typical of turbidites. Also present are some reasonably well-sorted feldspathic sandstone and conglomeratic sandstone interbeds which are lithologically similar to parts of the Matinenda Formation which occupies the basal part of the Huronian sequence in the west.

SECTION 5

Stobie, Copper Cliff, and Lower McKim Formation, Western Graham Township

The section is located north of Highway 17 in lot 10 of concessions II, III, and IV, Graham Township.

This section extends southward from the intrusive contact of the Creighton Pluton through the following: some 2,500 feet (760 m) of mafic metavolcanics and interflow metasediments, the Stobie Formation; 1,900 feet (580 m) of felsic and mafic volcanic rocks, the Copper Cliff Formation; and 2,800 feet (850 m) of greywacke, siltstone, and minor feldspathic sandstone, the McKim Formation.

The volcanic sequence shows a major transition from mafic metavolcanics in the lower part to felsic metavolcanics in the upper part. Numerous repetitions of cycles consisting of a lower sequence of flows and an upper sequence of metasediments, some beds which contain disseminated sulphides are within the mafic metavolcanic portion. The felsic metavolcanics of the Copper Cliff Formation include rhyolite flows, some of which have well-defined flow-layering and felsic pyroclastics that include lithic and crystal tuff.

The lower part of the McKim Formation consists mainly of medium- to thick-bedded greywacke which displays the graded beds, ripples, ripple-drift crossbeds, and Bouma cycles typical of turbidite deposits.

SECTION 6

Elsie Mountain and Stobie Formations, Central Denison Township

The section is located south from near the contact of the Nickle Irruptive approximately ¼ mile (0.4 km) east of the Crean Hill Mine, lot 4, concession V, and lot 4, concession IV, Denison Township.

The section comprises some 2,600 feet (780 m) of interstratified mafic metavolcanics and metasediments belonging to the Elsie Mountain and Stobie Formations. These rocks represent the lower part of the Huronian metavolcanic sequence, and consist of cyclic repetitions of mafic flows, greywacke, siltstone, and quartz-feldspar sandstone. Sudbury-type breccias are abundant, and coarse-grained gabbroic and anorthositic intrusions are present in the lower part of the section.

SECTION 7

Stobie, Matinenda, and McKim Formations, Central Denison Township

This section is located South from the Vermilion Mine, east of and approximately parallel to the Crean Hill-Victoria Mine road, central Denison Township.

This section includes some 5,000 feet (1 500 m) of interstratified mafic metavolcanics, greywacke, siltstone, and feldspathic sandstones that constitute the lower part of the Huronian succession in this area. The sequence represents part of the lateral facies transition from the dominantly metavolcanic rocks of the Elsie Mountain and Stobie Formations in the east, to dominantly feldspathic sandstones of the Matinenda Formation in the west. Approximately 2,600 feet (790 m) of laminated argillite, siltstone, greywacke, and feldspathic sandstone of the McKim Formation, which conformably and gradationally overlies the basal metavolcanic-metasedimentary sequence, were also measured.

SECTION 8

Stobie, Matinenda, and McKim Formations, Western Denison Township

The section is located west of and parallel to the Crean Hill-Victoria Mine road, western Denison Township.

This section is located near the northern margin of the Southern Province of the Precambrian Shield and includes the upper part of the Huronian volcanic-Matinenda-type sandstone sequence and the lower part of the McKim Formation. The lower 3,000 feet (900 m) is comprised of interstratified mafic igneous rocks of the Stobie Formation and feldspathic sandstone, greywacke, and siltstone of the Matinenda Formation. Sulphide-bearing metasedimentary strata are present throughout the section. This sequence represents part of the lateral facies transition in the lower Huronian from the dominantly volcanic-greywacke sequence in the east, to the dominantly feldspathic sandstone-conglomerate sequence of the Matinenda Formation in the west.

The upper part of the section includes some 3,000 feet (900 m) of greywacke, laminated argillite, siltstone, and feldspathic sandstone of the McKim Formation. This sequence consists of approximately equal proportions of the following: medium-bedded greywacke with the graded bedding, ripples, and Bouma cycles typical of turbidites; and finely laminated argillite-siltstone. This sequence represents part of the lateral facies transition within the lower McKim from dominantly turbidite-type greywacke in the east to dominantly "laminated" argillite and siltstone in the west.

SECTION 9

Drury Gabbro-Anorthosite Pluton, and Stobie and Matinenda Formations, Drury Township

The section is located from the Chicago Mine southward generally along the Fairbank Lake road, eastern Drury Township.

This section is located near the northern margin of the Southern Province and includes part of a layered Gabbro-Anorthosite Intrusion which occupies the contact zone between the Southern and Superior Provinces. The section traverses approximately 2,000 feet (600 m) of Gabbro-Anorthosite, some 2,200 feet (670 m) of interstratified mafic metavolcanics, greywacke, siltstone, quartz sandstone, and conglomerate, and about 400 feet (120 m) of feldspathic sandstone, argillite, and quartz pebble conglomerate. The interstratified volcanic and sedimentary rocks represent part of the lateral facies transition from the dominantly volcanic sequence in the east to that of sandstone and conglomerate of the Matinenda Formation in the west. Sudbury-type breccia bodies occur in the section, and obscure the

nature of the contact between the Gabbro-Anorthosite Intrusion and the overlying volcanic-sedimentary sequence.

SECTION 10

Stobie, Matinenda, and Lower McKim Formations, Western Drury Township

The section is located in lots 9 and 10, concession IV, Drury Township.

This section extends southward from the southern margin of the exposed Early Precambrian granitic basement rocks of the Superior Province through the lower part of the Huronian sequence. The section is located approximately 4½ miles (7 km) east of the Agnew Lake Mine that was developed to explore uranium-bearing conglomeratic rocks of the Matinenda Formation. The sequence exposed along this section represents part of the lateral facies transition in the lower Huronian from dominantly metavolcanics and associated greywackes in the east to dominantly quartz-feldspar sandstones and associated conglomerates and laminated argillites in the west.

The sequence comprises the following: some 800 feet (240 m) of interstratified mafic metavolcanics, greywacke and arkose of the Stobie Formation; approximately 1,500 feet (460 m) of interbedded feldspathic sandstone, quartz-pebble conglomerate, and pelitic rocks of the Matinenda Formation; and about 1,400 feet (430 m) of the McKim Formation pelite, greywacke, polymictic paraconglomerate, and possibly, several thin mafic volcanic flows.

SECTION 11

Matinenda and McKim Formations, Eastern Hyman Township

The section is located in lot 1, concession IV, and lot 1, concession III, Hyman Township.

The section is located approximately 1½ miles (2.4 km) east of the Agnew Lake Mine and extends southward from the Early Precambrian granitic basement rocks of the Superior Province to the north into the lower Huronian supracrustal rocks of the Southern Province to the south. Several hundred feet (90 m) of greywacke, siltstone, and arkose are in unconformable or fault contact with the granitic basement rocks. Intrusive into this sequence is a sill-like body of anorthositic gabbro that represents the westward continuation of the main gabbro-anorthosite mass located in Drury Township (see Section 9). Overlying this are some 2,000 feet (600 m) of interbedded sandstone, argillite and conglomerate of the Matinenda Formation and several thousand feet (900 m) of argillite and siltstone of the McKim Formation. The area is structurally complex with structural repetitions of stratigraphic units, and undoubted tectonic thickening and thinning.

SECTIONS 12a AND 12b

The Lower Part of the Huronian Sequence in the Agnew Lake Mine Area, Central Hyman Township

The section is located in north-central Hyman Township in the vicinity of the Agnew Lake Mines Limited uranium exploration development.

This section extends southward from deformed Early Precambrian granitic basement rocks through the lower part of the Huronian sequence. The Huronian rocks form the north limb of a tight faulted synclinal structure that represents the eastward continuation of the Porter Synclinorium. Numerous steep-dipping, east-northeast-trending faults, and more gently inclined thrust-type faults are present in the area. Movements on these faults have produced stratigraphic repetitions and omissions. Also, in the mine area, bedrock is poorly exposed and much of the descriptive material presented here is derived from diamond-drill logs filed in the name of Kerr Addison Mines Limited at the Resident Geologist's office, Ontario Ministry of Natural Resources, Sudbury.

A sequence of feldspathic sandstone, argillite, oligomictic quartz-pebble conglomerate, and polymictic conglomerate some 700 feet (200 m) thick lies on a deformed unconformity developed on Early Precambrian basement rocks. This sequence, which is correlated with the Matinenda Formation, contains several units of interbedded arkose and uranium-bearing quartz-pebble conglomerate.

Above this are some 60 feet (18 m) of pelite and sandstone, and 10 to 20 feet (3 to 6 m) of polymictic paraconglomerate. These rocks may represent the thin, northernmost wedges of the McKim and Ramsay Lake Formations respectively (Section 12b).

Overlying these, in apparent conformity, is a sequence some 1,300 feet (400 m) thick of sandstone, pelite, and mafic igneous rocks. The lower part of this sequence may be correlative with the Pecors Formation, the upper part, with the Mississagi Formation. The igneous rocks probably represent both basaltic flows and gabbroic intrusions. A sill-like mass of anorthositic gabbro similar to the anorthositic rocks at the base of the sequence in adjacent Drury and Denison Townships is present. This part of the section ends at a fault.

The upper part of the section (Section 12b), located east of the Agnew Lake Mine and south of the fault, traverses a sequence of argillaceous sandstone and pelite some 900 feet (270 m) thick and approximately 500 feet (150 m) of feldspathic sandstones that occupy the axial zone of the syncline. These rocks are tentatively correlated with the Pecors and Mississagi Formations.

SECTION 13

McKim, Ramsay Lake, and Pecors Formations, Graham Township

The section is located south from Highway 17 to McCharles Lake, south-central Graham Township.

This section encompasses the following: some 200 feet (60 m) of greywacke and argillite, the upper part of the McKim Formation; about 600 feet (180 m) of conglomeratic rocks of the Ramsay Lake Formation; and some 2,000 feet (600 m) of greywacke, siltstone, argillite, and feldspathic sandstone that represents most of the Pecors Formation. Graded beds, laminated beds, ripples, ripple-drift cross-lamination, and ball-and-pillow structures occur in the pelitic rocks. The contact between the McKim and Ramsay Lake Formation is conformable and transitional through a zone 30 feet (9 m) thick consisting of interbedded greywacke, subgreywacke, pebbly greywacke, polymictic paraconglomerate, and siltstone. The conformable nature of this contact is noteworthy, since it was long thought to represent the "great unconformity" between an Archean "Sudbury Series" and the Proterozoic Huronian sequence (Coleman 1914).

SECTION 14

McKim Formation, Graham Township

The section is located in western Graham Township from the Murray Fault south to the Vermilion River.

This section consists of some 3,000 feet (900 m) of strata in the upper part of the McKim Formation. The rocks consist of interbedded greywacke, siltstone, argillite, and impure sandstone that show graded bedding, ripples, ripple-drift crossbedding, laminated bedding, ball-and-pillow structures, Bouma cycles, and clastic dikes.

SECTION 15

Upper Pecors and Mississagi Formations, Louise Township

The section is located in lot 6, concession V, and lot 6, concession IV, Louise Township.

The section, measured by P. Palonen (1971), is located on the north limb of the West Lake Syncline and includes some 975 feet (295 m) of pelite and sandstone of the Pecors Formation and over 8,500 feet (2,600 m) of sandstone in the Mississagi Formation. The top of the Mississagi Formation, which is estimated to be about 10,000 feet (3,000 m) thick in this area, was not reached.

The upper part of the Pecors Formation is generally divisible into a lower unit consisting of laminated, thinly bedded argillite, siltstone, and fine-grained greywacke, and an upper unit some 300 feet (90 m) thick of fine- to medium-grained quartz-feldspar sandstone (greywacke, subgreywacke).

These rocks are conformably overlain by a thick-bedded, crossbedded feldspathic sandstone, the basal unit of the Mississagi Formation. The Mississagi Formation consists of a number of sedimentary cycles which vary in thickness from about 20 to 250 feet (6 to 76 m). The lateral extent of individual cycles is in the

order of several miles (kilometres). The base of each cycle is sharp and well defined, but there is no evidence for scoring or erosion at these contacts. Within each cycle, the rocks show increasing average grain size and sorting upward.

Stratiform zones of breccia consisting of sandstone fragments in a greywacke or subgreywacke matrix are present at the top of the measured section.

SECTION 16

Salmay Lake Formation and Matinenda Formation, Southwestern Hyman Township

The section is located west of John Creek Bay, Agnew Lake, in the southwestern corner of Hyman Township.

This section encompasses volcanic rocks, correlative with the Salmay Lake Formation to the west (Robertson 1970) and sedimentary rocks of the Matinenda and McKim Formations exposed in the axial zone of the Agnew Anticline, a tight, northeast-plunging (45°) fold of the Baldwin Anticlinorium system. Since the area is structurally complicated, all footages given are approximate.

Matinenda sandstone and conglomeratic rocks conformably overlie basal Huronian mafic metavolcanics and associated pelitic and conglomeratic metasediments. The Matinenda Formation is in turn conformably overlain by pelitic rocks of the McKim Formation. The Matinenda Formation in the section can be subdivided into the following: a lower unit of a coarse-grained feldspathic sandstone, conglomeratic sandstone, and oligomictic quartz-pebble conglomerate approximately 200 feet (60 m) thick; a middle unit, approximately 400 feet (120 m) thick of medium- to coarse-grained, crossbedded feldspathic sandstone; and an upper unit approximately 400 feet (120 m) of micaceous feldspathic sandstone with argillaceous partings and interbeds.

SECTION 17

Parts of the Salmay Lake Volcanic Sequence and Matinenda and McKim Formations, and a Gabbro-Anorthosite Pluton, Baldwin Township

The section is located south of the south shore of Agnew Lake, lot 9, concession V and VI, Baldwin Township.

The section is located on the north limb of the Baldwin Anticlinorium, a structurally complex area of major faults and tight folds. Two major faults exist in the section-area south of Agnew Lake. These trend ENE parallel to each other and are about ¼ mile (0.4 km) apart. To the south, a relatively uninterrupted sequence of Huronian metavolcanics is exposed that is probably correlative with the Salmay Lake Formation to the west (Robertson 1970), sandstone and conglomerate of the

Matinenda Formation, and pelite and sandstone of the McKim Formation. Gabbro-Anorthosite with felsic differentiates are present between the faults. To the north, along the shore of Agnew Lake there are brecciated McKim-type pelite and sandstone.

SECTION 18

Upper McKim to Lower Serpent Formations, Baldwin and Porter Townships

The section extends north from the north shore of Agnew Lake in northwestern Baldwin Township to Hunter Lake in southwestern Porter Township.

This section encompasses the following: about 100 feet (30 m) of greywacke, siltstone, and argillite of the upper McKim Formation: 100 feet (30 m) of conglomerate and sandstone of the Ramsay Lake Formation; 2,000 feet (600 m) of sandstone of the Mississagi Formation; 500 feet (150 m) of conglomeratic rocks of the Bruce Formation; 700 feet (200 m) of calcareous rocks of the Espanola Formation; and several hundred feet of sandstone of the Serpent Formation.

The section is located north of the Murray Fault on the south limb of the Porter Synclinorium. The thicknesses of many formations in this area are generally much less than in areas south of the Murray Fault (compare with Sections 15, 21, and 23). For example, the Mississagi Formation in areas north of the Murray Fault does not exceed 2,500 feet (760 m), whereas in areas to the south it is at least 5,000 feet (1 500 m) thick and possibly as much as 10,000 feet (3 500 m) thick. Similarly, the Espanola Formation, which is here approximately 700 feet (200 m) thick, is about 1,000 to 1,500 feet (300 to 450 m) thick in the south. The Bruce Formation shows the opposite thickness trend. In areas south of the Murray Fault, it seldom exceeds 300 feet (90 m) in thickness and is locally very thin or missing entirely. In the section it is nearly 500 feet (150 m) thick.

SECTION 19

Ramsay Lake and Pecors Formations, Baldwin and Shakespeare Townships

The section is located along the boundary between Baldwin and Shakespeare Townships and extends northward from Agnew Lake.

In this section are represented; some 270 feet (80 m) of conglomeratic rocks and sandstone of the Ramsay Lake Formation, approximately 200 feet (60 m) of pelite and sandstone of the Pecors Formation, and the lowermost few feet of the Mississagi Formation. These formations are exposed on the southern limb of the Porter Synclinorium north of the Murray Fault.

SECTION 20

Lower Part of the Mississagi Formation, May and Harrow Townships

This section is located in lot 3, concession I, May Township and lot 3, concession VI, Harrow Township.

This section includes some 2,400 feet (730 m) of the lower part of the Mississagi Formation which here comprises a number of cyclically repeated units that consist of interbedded siltstone and silty sandstone at the base passing upward into feldspathic sandstone at the top. Within each cycle, a general upward increase occurs in the average grain size and degree of sorting in the sandstone. Sandstones in the lower parts of cycles are medium-grained feldspathic protoquartzite and subgreywacke whereas in the upper parts, the sandstones are mainly medium- to coarse-grained, commonly pebbly, feldspathic quartzite and arkose. Minor amounts of sulphide minerals (pyrite, pyrrhotite) occur throughout the section and are concentrated in siltstone and silty sandstone interbeds. Specular hematite occurs in minor amounts as coatings on fracture joints, and grains, and as disseminated flakes.

The sandstones commonly show planar and festoon crossbeds, graded beds, and coarse laminations. Parallel-laminations, ripples, and slump structures are present in the silty interbeds.

SECTION 21

Upper Mississagi to Lower Gowganda Formations, Southwestern Merritt Township

This section is located near the southern end of Apsey Lake, lot 10, concession I, Merritt Township.

This section consists of: some 60 feet (18 m) of feldspathic sandstone of the uppermost part of the Mississagi Formation; 160 feet (48 m) of conglomeratic rocks of the Bruce Formation; approximately 1,300 feet (400 m) of calcareous pelite, silty limestone and sandstone of the Espanola Formation; 1,000 feet (300 m) of sandstone of the Serpent Formation; and about 70 feet (20 m) of conglomeratic rocks of the basal part of the Gowganda Formation. The section is located south of the Murray Fault on the northern limb of the Bass Lake Syncline. This fold is a relatively open, doubly plunging, basin structure located approximately midway between the northern and southern boundaries of the eastern Southern Province.

The contact between the Espanola and Serpent Formations is conformable and gradational over a stratigraphic interval of several hundred feet (90 m). The Mississagi-Bruce and Serpent-Gowganda contacts are abrupt, and evidence suggests that both represent erosional disconformities.

SECTION 22

Upper Bruce to Lower Lorrain Formations, Southeastern McGregor Bay Area

This section is located near the south shore of McGregor Island along the Sampson Island Channel.

This section encompasses some 300 feet (90 m) of conglomerate of the upper Bruce Formation, 1,300 feet (400 m) of silty limestone calcareous siltstone and sandstone of the Espanola Formation, 1,900 feet (580 m) of feldspathic sandstone of the Serpent Formation, 3,200 feet (980 m) of conglomerate, laminated argillite and siltstone, and sandstone of the Gowganda Formation, and about 200 feet (60 m) of feldspathic sandstone of the lower Lorrain Formation.

Brecciated, highly contorted calcareous rocks of the Espanola Formation abruptly overlie the massive Bruce conglomerate. Much of the disruption in the lower Espanola sequence is probably attributable to soft-sediment deformation. The contact between the Espanola and Serpent Formations is conformable and gradational over a stratigraphic interval of several hundred feet (90 m) but a thin calcareous unit provides a convenient marker to define the top of the Espanola Formation. The contact between the Serpent and Gowganda Formations is conformable and gradational through a sequence of interbedded conglomerate and sandstone some 65 feet (20 m) thick. The Gowganda Formation can be subdivided into two main parts, a lower unit, 1,900 feet (580 m) thick of interstratified conglomerate, laminated argillite, siltstone and sandstone, and an upper unit 1,300 feet (400 m) thick of sandstone and siltstone with well-developed slump structures. Feldspathic sandstone and minor siltstone of the Lorrain Formation conformably overlie the Gowganda Formation.

SECTION 23

Upper Mississagi to Lower Serpent Formations, Northeastern McGregor Bay Area

This section is located north from the north shore of McGregor Island onto the mainland.

The section is located on the north limb of the McGregor Bay Anticline, a major east-west trending subisoclinal fold in the Huronian sequence of the McGregor Bay area of Lake Huron. In the section occurs the following: 175 feet (55 m) of sandstone of the upper Mississagi Formation, several hundred feet (90 m) of conglomeratic rocks of the Bruce Formation, 1,400 feet (430 m) of calcareous pelite and sandstone of the Espanola Formation, and about 150 feet (46 m) of sandstone of the Serpent Formation. These rocks are well exposed in shoreline and island outcrops. The area is structurally complex. Movement on faults parallel to stratigraphic trends has produced stratigraphic repetitions, especially in the lower part of the section.

SECTION 24

Upper Espanola to Lower Lorrain Formations, Northwestern McGregor Bay Area

This is a generally north-south section along the western side of the channel between Iroquois Island and the mainland, and the western end of Iroquois Bay.

The section is located near the southern margin of the north limb of the McGregor Bay Anticline (or the south limb of the complimentary La Cloche Syncline), that is an upright, subisoclinal major fold whose axis plunges gently eastward. Well exposed in a clean, wave-washed, continuous outcrop are some 800 feet (240 m) of limestone, pelite, and sandstone of the upper Espanola Formation, 1,300 feet (400 m) of feldspathic sandstone of the Serpent Formation, 2,800 feet (850 m) of conglomerate, pelite, and sandstone of the Gowganda Formation, and several hundred feet of sandstone of the lower part of the Lorrain Formation.

The rocks of the Espanola Formation are characteristically carbonate bearing and show structures such as thin, laminated bedding, ripples, ripple-drift cross-laminations, slump structures, and desiccation cracks. The contact with the overlying Serpent sandstone is conformable and gradational over a stratigraphic interval of some 50 feet (15 m).

The Serpent Formation consists mainly of crossbedded feldspathic sandstones which display cyclic repetitions of thick-bedded and thin-bedded units. Several calcareous members are present in the upper part of the Serpent Formation. The contact with the overlying Gowganda Formation although apparently conformable, is irregular and evidence exists for large-scale slumping.

The Gowganda Formation can be subdivided into two units of approximately equal thickness. The lower unit comprises cyclically repeated conglomeratic and pelitic members. The conglomeratic members consist mainly of polymictic paraconglomerate and orthoconglomerate that are reasonably well-bedded in this section. The pelitic members are typically finely laminated and display ripples and ripple-drift cross-laminations. The upper unit of the Gowganda Formation consists of laminated pelite members and sandstone members with spectacular slump structures.

The lower part of the Lorrain Formation, which lies conformably above the Gowganda, consists of interbedded sandstone and silty sandstone with well-developed bedding, crossbedding, and ripple-drift cross-laminations.

SECTION 25

Gowganda Formation, Whitefish Falls Area

This section is located along Highway 68 south of the village of Whitefish Falls.

This section is located on the south limb of the La Cloche Syncline (on the north limb of the complimentary McGregor Bay Anticline) a major subisoclinal fold which trends east-west along the North Shore of Lake Huron. The section in-

cludes the upper part of the Serpent Formation, a sequence of crossbedded feldspathic sandstone, conglomerate, pelite, and sandstone of the Gowganda Formation, and a few hundred feet of feldspathic sandstone of the Lorrain Formation.

The Gowganda Formation can be broadly subdivided into a lower unit approximately 2,000 feet (600 m) thick consisting of cyclic repetitions of conglomerate and laminated argillite-siltstone, and an upper unit approximately 1,800 feet (550 m) thick consisting of sandstone and siltstone with abundant slump structures.

SECTION 26

Lorrain Formation, Mongowin and Curtin Townships

The section is located along Highway 68 in Mongowin and Curtin Townships.

This section includes over 7,000 feet (2 100 m) of the Lorrain Formation that is exposed on the near-vertical north limb of the La Cloche Syncline in Mongowin and Curtin Townships. The lower contact of the Lorrain Formation with the Gowganda Formation is the Charlton Lake Fault, but apparently little of the basal Lorrain Formation is missing. The upper contact with the Gordon Lake Formation is covered by surficial deposits and the waters of Frood Lake.

The Lorrain Formation in this section, and in the report-area as a whole, can be subdivided into a number of members on the basis of colour, mineralogy, texture, and sedimentary structures. The members are in ascending order: about 450 feet (137 m) of interbedded, medium-grained pink arkose and grey silty sandstone; 950 feet (290 m) of coarse-grained arkose; 2,000 feet (600 m) of coarse-grained, greenish, micaceous sandstone; 1,800 feet (550 m) of medium-grained buff, hematitic, micaceous sandstone; 1,600 feet (490 m) of white, medium-grained, aluminous sandstone; and several hundred feet (90 m) of white and reddish fine-grained orthoquartzite.

SECTION 27

Part of the Gordon Lake Formation, Curtin Township

The section is located in western Curtin Township along the shore of Frood Lake.

This section includes part of the Gordon Lake Formation in the faulted axial zone of the La Cloche Syncline, a major subisoclinal fold which trends east-west along the North Shore of Lake Huron.

The conformable, gradational contact between the Lorrain and Gordon Lake Formations is exposed on the north shore of Frood Lake. On the south shore of Frood Lake, some 1,300 feet (400 m) of siltstone, sandstone, and chert-like rocks of the Gordon Lake Formation are in fault contact with north-facing rocks of the Lorrain Formation which constitute the south limb of the La Cloche Syncline.

SECTION 28

Upper Gordon Lake and Bar River Formations, Narrow Bay Area

The section is located south from the south shore of Narrow Bay across Frazer Point along the Hydro Electric Power Commission of Ontario transmission line.

The section is located on the north limb of the Frazer Bay Syncline, a major subisoclinal fold located in the southern part of the exposed Southern Province approximately 8 miles (12.8 km) northwest of the Grenville Front. Included are about 600 feet (180 m) of siltstone, chert-like rocks, and fine-grained sandstone of the Gordon Lake Formation, and some 3,000 feet (900 m) of sandstone and siltstone of the Bar River Formation, the uppermost formation of the Huronian Supergroup. The Gordon Lake is characterized by thinly bedded, very fine-grained chert-like rocks, and by a variety of well-preserved structures such as desiccation cracks, ripples, ball-and-pillow structures, and "chert" breccias. The Bar River Formation contains very pure orthoquartzites and hematite-rich siltstones.

The contact between the Gordon Lake and Bar River Formations is conformable and gradational over a stratigraphic interval of several hundred feet (metres). Consequently, the lower boundary of the Bar River Formation is arbitrarily placed at the first appearance in the section of relatively thick-bedded orthoquartzite.

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